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## DRY POLISHING OF OPAQUE MINERALS

HORACE J. FRASER AND R. VON HUENE,

*California Institute of Technology, Pasadena, California.*

### ABSTRACT

The process of polishing opaque minerals is restudied with the hope of speeding up the process without undue loss of quality. It is found that the physical character and structure of a lap have a marked effect, both in grinding and polishing. The composition and structure of laps found satisfactory are presented. Determinations are given of the rate of removal of material during the various stages of grinding and polishing. Various types of mechanical heads are described, the method of charging laps is discussed in detail, and the complete process of mounting and polishing is outlined, together with illustrations of the various types of polish.

### INTRODUCTION

The literature dealing with the study of ore minerals contains several excellent descriptions of various methods for polishing opaque minerals (1). These methods differ greatly in the character and relief of the surface which they produce, the freedom of that surface from pits and scratches, the time required to attain that surface, the type and size of abrasive used, and the type of mounting necessary. Cloth-lap polishing was introduced by the metallurgists and long considered satisfactory by them because, in general, they dealt with material which either showed relatively small variation in relief, or whose texture was such that differences in relief were not accentuated by polishing. The cloth lap, or buff, is still widely used in polishing glass, stone, plastics, metals, and those mineral surfaces where variation in hardness or texture will not produce excessive relief. Although this method produces much pitting, plucking and scratching, as well as obscuring the contact relationships between minerals of different hardness, it still is used in many laboratories because the necessary equipment is simple, the materials inexpensive, and the technique easy to acquire. The other extreme in polishing is represented by the high quality polish attained on a metal lap, such as the lead lap. The surface produced by this method is practically free from relief and under proper conditions is relatively free from scratches and pits. How-

ever, practically everyone agrees that the use of this method is an art which can only be acquired by a long and tedious apprenticeship. Moreover, the method is inherently slow, requires very precise sizing of the abrasive, critical control of the character and degree of lubrication, and close supervision by the operator. Although the method gives unequalled results under favorable conditions, the time required for a polish suitable for ordinary work is too great to justify the use of this method in routine work.

Dry polishing was investigated with the hope of obtaining a satisfactory polished surface more quickly than by the lead-lap method, and a surface of much less relief and more definition than that produced by cloth polishing. In the course of the investigation much was learned regarding the mechanism of polishing, and several rather radical departures from standard practice were successfully tried. Although any method will continually undergo some changes, the general procedure outlined in the following pages has been in use now for over three years in our laboratories, and the specific procedure has given excellent results during the last year.

#### THEORY OF POLISHING

The principles involved in the development of a polished surface have been much discussed in the literature since such surfaces play a vital role in many fields. Some investigators consider that polishing consists of two processes, i.e., a removal of material by pitting or cutting, and a smoothing of the remaining surface by flowage of the material from high points to low points on that surface. Others consider that the process of polishing consists entirely in the removal of material, first by pits and then by cutting scratches successively smaller in width until they become sub-microscopic and consequently invisible at the ordinary magnifications.

The metallurgists have been strong advocates of the plastic deformation theory as the cause of the final polish. This is understandable since metals yield by flow much more readily than do most of the relatively brittle minerals. Moreover, it has been established that some of the polished surfaces achieved by cloth polishing are in reality films of metal oxide smeared over scratched metal. In fact, oxidation may be so rapid during polishing of metals that it is necessary to carry on the final polishing under benzene (2).

The geologist, on the other hand, who sees in a polished surface many delicate intergrowths and textures, finds it very difficult to believe that there has been any notable displacement of material. Recently this controversy has been revived through the publications of Bowden and Hughes (3). Investigations carried on in our laboratory left little doubt



but that, with some methods of polishing at least, there is displacement of surface material. With other methods of polishing a different character of surface seems to be developed. Details of this investigation are presented in a separate paper.

The polishing process ideally consists of the cutting away of material by very sharp points. The perfect lap surface would be one on which these points—as represented by the corners of the abrasive—are all firmly held in one plane so that they would be in a position of maximum cutting efficiency, and at such a height that they would remove a uniform depth of cut at each operation. Moreover, they should be replaced as rapidly as they become worn or broken. The choice of an abrasive must be governed by several considerations. Its efficiency as a polishing agent is determined by its melting point rather than its hardness (2). However, the shape of the grains and their cleavability have an important bearing on the effective, useful life of any abrasive.

Anyone who examines a polishing cloth under the binocular microscope can immediately see why it makes such a rapidly cutting medium when treated with the proper amount of abrasive. The threads are so spaced that the grains of abrasive drop in between them and are held in position for cutting. If the cloth is strong enough, the abrasive grain cannot roll or move but is forced to stay in that position. Usually the cloth is backed by a hard surface so that the abrasive cannot be pressed into that surface and must rest on it and thereby remain available for cutting. The cloth lap, however, is also noted for the amount of relief which it produces. This is probably due to two factors. First, the bending of the cloth as it passes from hard to soft mineral and secondly, to the loose ends of the cloth fibers which become charged with abrasive and whip around on the surface. In the writers' experience this second fact is the more important one in producing relief. The chief asset of the cloth-lap method is its speed and this is due to the efficient method of maintaining abrasive in contact with the surface to be cut.

On a lead-lap surface the abrasive is either held in position for cutting by being embedded in the lead, or else it rolls on the surface and gouges by pitting, rather than cuts by scratching. The hardness of the lead in the lap is important. If the resistance to embedding offered by the lead is not sufficiently great, the hard surface of the mineral will push the abrasive down into the lead thereby nullifying its cutting action. If the lead is too hard, the abrasive will not be sufficiently embedded and consequently will scratch. The quality of bonding between the abrasive and the lap is also related to the physical properties of the metal, of which hardness is one characteristic. Various investigators have attempted to control this bonding and the hardness of the lap surface by using other materials such

as tin, copper, pitch, or various plastics. If the mineral surface is too soft, it will be deeply scratched, if it is too hard, the tendency will be to avoid any cutting. Effects of this principle are well known to anyone who has tried to polish native silver or chromite on a lead lap.

Another critical feature in any polishing process is the lubricant. The reason for lubricating is largely to keep down the heat produced at the point of contact between the abrasive and the surface, and to assist in removing the products of polishing. Local temperatures may be of the order of 600° C. or more, under conditions of boundary lubrication with a mineral oil (4). During grinding, or the coarser stages of polishing, when the rate of the removal of material from the surface is particularly rapid, the lubricant may perform a useful function.\* During the final stages, when the amount of material removed is very small and the abrasive is relatively small in diameter, the presence of a film of lubricant which tends to float the polishing surface over the lap surface and to prevent proper cutting action, may become decidedly detrimental. In fact, one reaches a stage where the presence of any lubricant defeats polishing. It is for this reason that the control of the lubricant is so critical during the final stages of polishing on a lead lap.

The two major functions of lubrication, namely dispersal of heat and waste products, can be achieved by methods other than by the use of a liquid. Picture a cutting surface consisting of a series of points which project above the level of that surface. Spaced between these points is a set of "skids" which will control the depth of cutting of the points and yet leave no contact between most of the cutting surface and the surface which is being cut. The heat developed by the cutting action can be dispersed through the layer of air separating the two surfaces. The products of cutting, which must of necessity be smaller than the points producing the cuts, can likewise drop into the spaces between the "skids" and be removed from the surface of action.

The ideal lap surface then would consist of a series of hard smooth points or skids between which is a softer material to hold the abrasive or spaces in which the abrasive can be fixed. There are a number of different materials which have this general type of structure.

Certain types of papers and other materials made from wood pulp, such as pressboard, celotex and some kinds of wallboard consist of a mass

\* Measurements made in our laboratory indicate that the rate of removal of material from a section 1.5 inches in diameter, is of the following order of magnitude; grinding on a bronze lap removes about .001 inch per minute, fine grinding on a wooden, celotex or lead lap, about .0005 inches in 10 minutes, and polishing on a celotex lap removes .00005 inches per hour. These rates of course fluctuate with the size and composition of the specimen as well as with the general lap conditions.



of interwoven wood fibers with a matrix of softer and much finer grained material. This is not true of all papers, many of which have been sized by the addition of clay or other bonding material which has filled the pores. The character of a material and its suitability as a polishing medium are readily determined by a binocular examination. The desirable structure is a criss-crossed mat of fibers which act as skids, and a matrix soft enough to hold the abrasive. It is essential to avoid a structure in which fibers have a tendency to lift free at the ends, since this develops excessive relief.

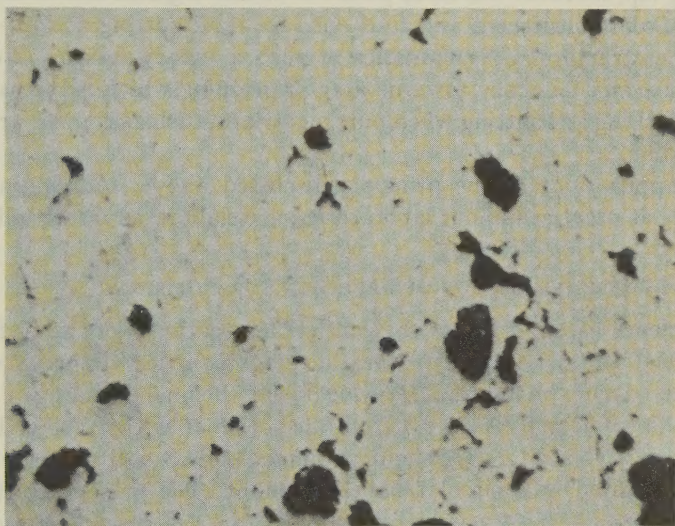


FIG. 1. Bronze lead lap. White is harder bronze, dark gray and black areas are lead impregnated with abrasive. Mag. 48 diameters.

A suitable structure can also be developed in certain types of alloys where a hard constituent forms the skids and a softer material the bonding agent for the abrasive. The best material of this type found to date is a bronze lead, a photograph of which is shown in Fig. 1. This material is prepared as follows:

To a given amount of government bronze while in the ladle, there is added approximately 14 per cent, by weight, of lead and 1 per cent of nickel. The material is then cast and machined in the usual fashion. This type of lap avoids the plucking, pulling and pitting characteristic of many other types of grinding laps.

A comparison of this concept with that held for bearing metals is both interesting and instructive. According to Bassett (5) it is essential that any satisfactory bearing metal be composed of a hard constituent sup-

ported or embedded in a softer matrix. Bassett also holds that the hard constituent stands in relief above the soft matrix and carries the load, whereas the lubricant is held in the hollows formed by the soft constituent. Kyropolous (2) disagrees with this last concept and has demonstrated that in a satisfactory bearing metal, the soft constituent possesses a much greater thermal expansion, so that in use, it expands above the elevation of the harder constituent and actually carries the load. When cooled it contracts so that its elevation is lower than the harder constituent. If this phenomenon occurs to an important extent in a binary grinding lap, its effect will be to push the abrasive grains above the level of the harder constituent and thus enhance their cutting action. Moreover, the structural characteristics of such a binary mixture strongly counteract any tendency towards drag or gripping which is the cause of much plucking and pitting when pure metal laps, such as copper, are used for grinding.

The applications of the principle discussed above, to grinding and polishing as practiced in our laboratories, are elaborated in the following pages.

#### PREPARATION OF SPECIMEN FOR POLISHING

Experience has shown that the gentler the treatment of the surface to be polished, throughout the preparation stages, the less difficulty will be encountered from pitting and breaking during the final polishing.

The chip to be polished is cut from the specimen with a Felker DiMet diamond saw. The edges are slightly rounded and after drying, the specimen is mounted in a circular bakelite mount. The present method of mounting has not been materially changed from that described by Murdoch (6). The specimen is numbered as follows:

The symbol and number are stamped on a strip of aluminum, or copper, about one quarter inch wide and one inch long. The ends of the strip are then bent at right angles and the strip stuck with rubber cement to the end of the piston which has a central shoulder 0.8 inch in diameter and 0.065 inch high. The piston and label are then inserted into the mold containing the sample and powdered bakelite. The number is thus mounted on the bottom side of the specimen, in a circular depression one sixteenth of an inch below the rim.

#### *Impregnation of Specimen.*

Immediately upon removal of the mounted specimen from the molding press, the hot, rough surface of the ore specimen is given a liberal coating of bakelite varnish No. B-V 1115, to a depth of about  $\frac{1}{8}$  of an inch. It is not essential for the success of the impregnation that the specimen be hot but it is believed that a better bonding is attained when the specimen has been preheated. The mounted specimen is then placed coated side up on a small vacuum plate [Fig. 2], the plate covered with a small glass jar and a



vacuum created by water passing through an ordinary air aspirator. The bakelite varnish immediately begins to froth and the vacuum treatment is continued as long as the frothing lasts. This usually requires about one and one half minutes at which time the vacuum in the jar is equivalent to about 4 cm. of mercury. At this time the bakelite froth collapses and forms a thin film over the surface of the specimen. Air is then permitted to enter the jar, the specimen removed, the surplus bakelite wiped off with absorbent paper and the specimen placed on a hot plate maintained at a temperature of between 120 and 140° C. for a period of at least 12 hours, after which it is ready to grind.

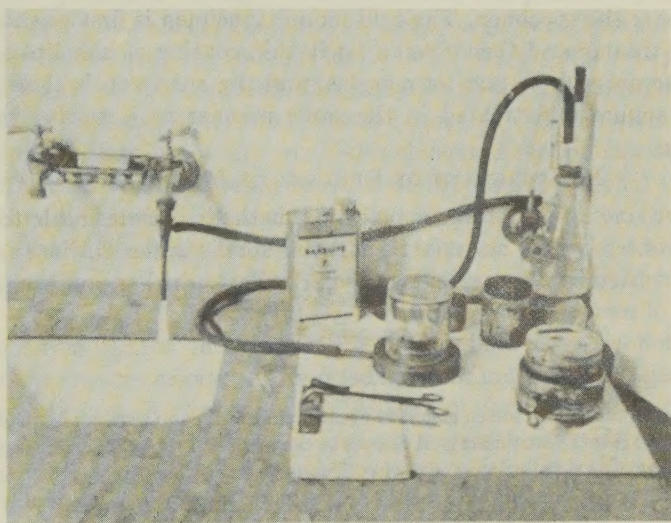


FIG. 2. Bakelite vacuum impregnation apparatus.

Specimens which are unusually fragile or porous may be given an impregnation treatment prior to mounting. The cut and trimmed specimen is first thoroughly washed with bakelite-thinner or with banana oil and is then placed in a container under about  $\frac{1}{4}$  inch of bakelite varnish. The vacuum is then applied in the usual manner until the varnish froths vigorously. Air is then admitted, the specimen removed and placed on a piece of paper on the hot plate and heating continues until the bakelite is thoroughly hardened. The time for this treatment varies greatly depending on the porosity and thickness of the specimen and the thickness of the bakelite coat. The maximum time is required for the hardening of impregnated pellets of mineral products prepared after the procedure described by the Lake Shore staff (7). This drying time ranges between a

minimum of about 12 hours to a maximum of 5 days, but it must be continued until the bakelite is thoroughly hardened or else the benefits of the procedure are nullified.

Pre-mounting impregnation of specimens has the additional advantage that the film of bakelite acts as a strong enveloping bond to prevent the specimen from disintegrating during mounting or during the subsequent polishing procedure. Consequently its use is recommended for friable specimens although they may have very low porosity. During the grinding and polishing process it sometimes is necessary to remove a layer of the mineral thicker than the depth of impregnation to get below the deep pits, i.e. those deeper than 0.01 inch. In such cases it is advisable to re-impregnate the specimen. The cold-mount specimen is first washed with bakelite-thinner and then given a fairly thin coating of bakelite so as to cover the ore sample and its margins, and the specimen is then placed under vacuum and treated in the same manner as a newly mounted specimen.

#### MEASUREMENT OF REMOVAL OF MATERIAL

In studying any grinding or polishing methods it is desirable to know the rate of removal of material from the mineral surface. Ordinary micrometric methods are not satisfactory particularly during polishing, when the rate of removal is very slow.

The following method provides a convenient means of accurately measuring the amount of removal between any stages.

A piece of 250-mesh Tyler screen is soldered onto a piece of tin and then cut in quarter-inch strips at an angle of approximately 14 degrees to the mesh line. The cut surface is carefully filed until there is no distortion of the wire. The diameter of this wire is about 1.6 thousandths and the opening between wires is 2.4 thousandths of an inch. A strip of this mounted screen is bent to a right angle and placed vertical beside the specimen in the mold and both mounted together.

During grinding and polishing the appearance of this strip at any time is similar to Fig. 3, where the rounded areas are the upright wires and the elongated areas are transverse sections of the other wires inclined 14 degrees to the plane of the section. As the surface is cut down, the absolute position of the rounded sections shifts slightly and that of the elongated sections very substantially with respect to the rounded sections. The nature of these changes are shown in Fig. 4, and the mathematical relations are as follows:

$$\sin \alpha = \frac{X}{T+t} \quad \therefore X = \sin \alpha (T+t) \quad \text{and} \quad \cos \alpha = \frac{R}{X}$$

$$\therefore R = \cos \alpha \cdot X = \cos \alpha \cdot \sin \alpha (T+t) = \frac{(T+t)}{L} \cdot W \cdot \cos \alpha$$

or

$$R = \frac{(T+t)w}{L} \cdot \cos \alpha.$$



Where  $W$  is a diameter of wire as measured on photograph, either as small axis of projection of inclined wire or diameter of upright wire.

$L$  is length of long axis of inclined wire as measured on photograph.

$T$  is travel of inclined wire as measured on photograph.

$t$  is travel of upright wire as measured on photograph.

$w$  is actual diameter of wire (for 250 mesh screen  $w$  is 0.0016 inch).

$\alpha$  is angle of inclination of wire to surface of section.

$R$  is thickness of material removed from polishing surface.

For accurate measurements of the removal of material, a photograph is taken at the beginning of the polishing process and another at the desired interval, the photographic conditions remaining constant. The first negative is projected through an enlarger and the position of the wire sections traced on a sheet of paper. The second negative is then projected, the paper moved until the rounded sections coincide and the new position of the elongate sections marked. The value for  $R$ , the amount of material removed, is then obtained from the above equation. For less precise work the change in position of any particular elongated section can be measured with respect to any rounded section on the assumption that the shift in position of the rounded section is not material. In general, the travel of the point of an elongated section from opposite one wire to opposite the next, represents a removal of about one thousandth of an inch.

### GRINDING

After the specimen has been mounted and impregnated it is necessary to remove the rough edges before it enters the next stage. The top and bottom edges of the cylindrical mount are rounded off on an old bronze lap using 400 carborundum abrasive and a copious supply of water. The face of the specimen is not touched on the lap, otherwise it will be deeply pitted by the action of this abrasive.

The coarse grinding is next done on a bronze lap using water as a lubricant and 800 crushed corundum as an abrasive. Specimens are held in the low pressure mechanical head (see Fig. 5). Grinding is continued on this lap until the front and back sides of the specimen are parallel, and until the face of the sample has a uniform matte surface. The pits that go to make this matte surface should be uniform in diameter and depth. The ordinary specimen requires about 5 minutes on this lap to produce a surface satisfactory for the next step.

### *Mechanical Polishing Equipment.*

All of the mechanical grinding and polishing equipment in our laboratories has the same type of mechanism for driving the laps. The mechanical heads which hold the specimens differ radically and deserve a brief explanation.

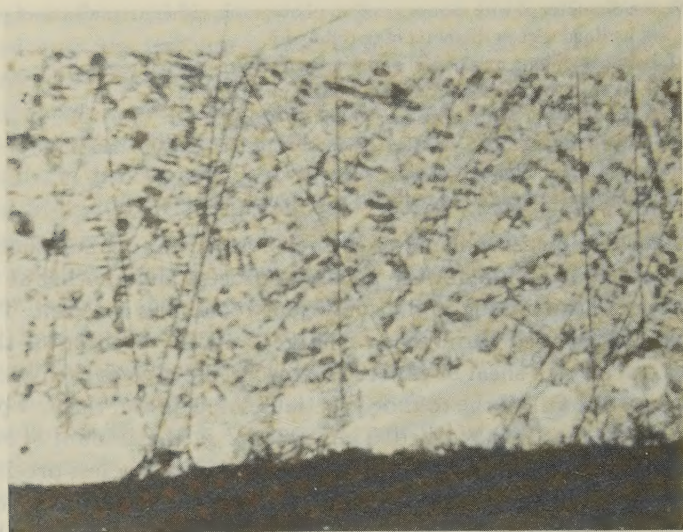


FIG. 3. Polished cross-section of measuring screen. Circular and elongated gray areas with white rim are wires. Mag. 48 diameters.

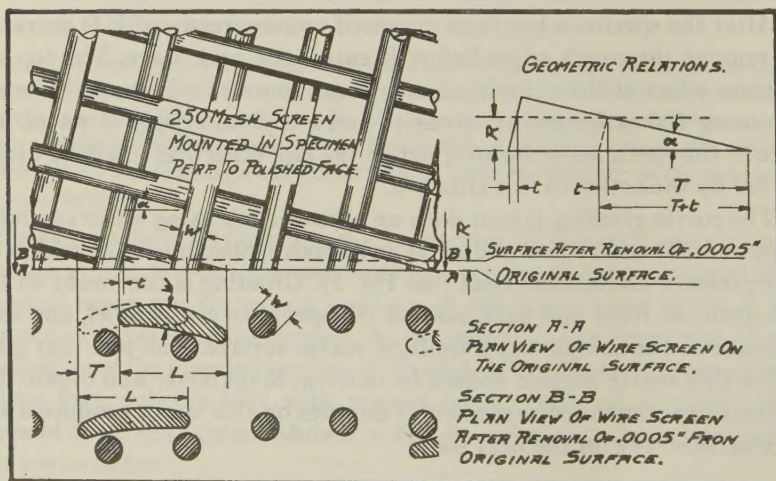


FIG. 4. Diagrammatic section of measuring screen.



The laps, 12 inches in diameter, are screwed on a spindle running in the standard bearings of a Ford model *T* front wheel. On the lower end of this spindle is a compound four groove pulley. Each lap is driven by a standard  $\frac{1}{4}$  H.P.A.C. motor which likewise has a four diameter pulley mounted on its shaft. The drive is by a V-belt which runs over an idler pulley kept tight by a spring—see the drive mechanism of a separate machine in the left background of Fig. 5.



FIG. 5. Low pressure mechanical grinding and polishing equipment.

### *Low Pressure Head.\**

The low pressure mechanical head (Fig. 5) has four specimen holders. Each holder has a piston operating against a coil spring or weight, inside a closely fitted cylinder. On the outside of this cylinder there is a sliding

\* Assembly drawings of any of this equipment are available on request from either author.

sleeve, clamped by a wing-nut bolt and band at the top, whose inside diameter is slightly greater than the mounted specimen. These sleeves are adjusted to a height of about one sixteenth of an inch above the lap. The entire head can be lifted by the upper lever when it is necessary to remove the specimens, and the pressure on the specimens adjusted by the amount the head is lowered onto the springs after the pistons come in contact with the specimens, or by the amount of weight, ranging from one-half to three pounds, placed on each piston. The elevation of the entire head is controlled by the adjusting collar on the main shaft.

The head is not mechanically driven but turns owing to the friction between the specimens and the lap. The speed of the head is controllable

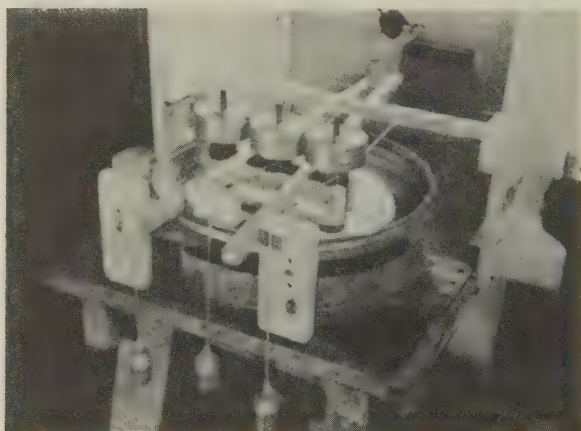


FIG. 6. High pressure mechanical polishing equipment.

by adjusting the length of the two governor arms which press against a brake band on the main shaft, but in practice this adjustment is rarely changed. This unit gives three motions; the lap is driven by the motor, the entire head spins by lap friction, and each specimen is turned within its own sleeve by friction. Since the pressure on the specimen, ranging from one-half to three pounds per specimen, is applied perpendicular to the bottom surface of the specimen, and since, if the specimen tries to tip, all of this pressure is concentrated on the opposite edge in opposition to the tipping action, the grinding action results in the development of parallel top and bottom surfaces. It is desirable to achieve this as soon as possible in all mechanical polishing.

#### *High Pressure Head.*

The high pressure head was developed to obtain a mechanical motion



as comparable as possible to that found most satisfactory in hand polishing and to permit as great a variation as necessary in the speed and pressure during polishing.

Each specimen holder follows an elliptical path from the edge of the lap toward the central part and back again. This is achieved by having the entire head driven by an eccentric, seen in the background of Fig. 6. The specimen which rotates freely inside its sleeve holder is pressed on by a piston weighted by one or more lead weights. A loop of cord passes once around the piston and is also weighted. As the piston and head are driven back and forth, the cord turns the piston through 90° and the weighted specimen likewise turns. These heads are simple to construct, give a very effective polishing action, and will operate with little attention over long periods. While the use of a mechanical head is not essential in polishing, it not only saves much time but also gives more consistent results.

#### SEMI-POLISHING

Up to this point the treatment of all specimens is essentially the same. Beginning at this stage, the methods and time required to prepare the specimen for a final polish vary greatly with different types of material. Consequently three different procedures have been adopted. The choice between these is based largely on experience.

##### *Celotex Lap Method.*

For the majority of specimens the next step of grinding or semi-polishing is usually carried out on a worn celotex lap. The rough side of the lap is first washed with a few drops of kerosene and wiped dry with a clean cloth. It is then lightly smeared with a small amount of a paste composed of Dynamo oil and No. 800 crushed corundum. This paste is applied lightly with a cloth swab and the lap is then re-wiped with a clean cloth until it is almost dry. It should have a slight oily reflection which can be tested for by touching the lap lightly with a finger and observing the oily film left on the finger. All of this is carried out while the lap is running. Specimens are ground on this lap using the low pressure head, until no further improvement is noticed in the specimen. Ordinarily this requires from 5 to 10 minutes but may be longer depending on the specimen.

The term celotex as used in this paper refers to celotex panel board which is softer than the commercial grade of hard board and has not been oil tempered. Equally satisfactory material is also sold under the trade name "masonite."

##### *Wooden Lap Method.*

Specimens of certain minerals characterized by brittleness or good cleavage, particularly from certain localities, show an undue amount of

plucking and pitting, which cannot be removed by additional grinding, when polished on the celotex lap. Experience has shown that these minerals may sometimes be greatly improved by using a wooden lap. The type which we have adopted is made of ordinary  $\frac{1}{4}$  inch ply wood and is cut and fastened onto the base in the same fashion as the celotex lap. The procedure for cleaning and treating this lap with abrasive is identical to that described above for the celotex lap. We do not understand why this lap avoids the plucking and pitting of other types, but experience has shown that it will produce results where all others fail completely.

#### *Lead Lap Method.*

The use of the lead lap in grinding is recommended for certain types of specimens typified by a fine grained distribution of brittle sulphides enclosed in talcose, or clayey matrix, in quartz. Some of the epithermal silver gold ores and some mill products, particularly where sericite forms an important part gangue, are best treated by this method. With specimens of this type the celotex lap seems either to pluck out the sulphide grain or else cut it down rapidly and cover it with a coating of grinding debris. It is a curious behavior not in accordance with the usual characteristics of the celotex lap. The lead lap used is 12 inches in diameter and has  $1/16$  inch concentric grooves spaced at  $\frac{1}{4}$  inch intervals. The lap is dressed for grinding in identically the same manner as a celotex lap, but the specimens are polished with a weight of about 3 pounds to the specimen and are not rotated any more than is absolutely essential. The lead lap turns at about 500 r.p.m. Cutting on this lap is much slower than on the other laps and specimens which require this treatment are usually run for a total of 30 minutes or more.

#### *Summary.*

The fine-grinding or semi-polished stage is the most critical one in the preparation of a polished surface. No hard or fast rules can be laid down for the behavior of any mineral, as the grain size, mineral association and texture are variables whose total range is greater than that of mineralogical differences. Moreover, there may be a wide variation in the behavior during polishing of what appears to be similar ore from different localities. Past and current experience must be the guide as to which method of grinding will prove most satisfactory. However, it must be emphasized that time cannot be saved at this stage because the amount of material removed during the final polishing is so small that pits left during fine grinding are not removed during any reasonable period of final polishing. Flat, shallow pits can be polished out but deep pits must be ground out at this stage.



# FINAL POLISHING

The final polish on all types of specimens is done on a celotex lap using an abrasive which is composed of approximately two parts of tin oxide to one part talc, and held on the lap by a celluloid cement. This abrasive mixture is composed of 8 grams of cellulose acetate, 25 grams of tin oxide (putty powder), 15 grams of talc and sufficient acetone to fill a 250 cc. flask. The mixture is kept tightly stoppered. Graphite may be substituted for talc by using a mixture containing one part graphite to seven parts tin oxide. The surface of the polishing lap is prepared as follows:

If the lap has been running it is first cleaned, using acetone and a stiff bristled brush to remove any debris, grease or other material which may have accumulated on the lap surface. Next, while the lap is still turning it is scrubbed fairly roughly with a steel-bristled hand brush, or scraped with the sharpened edge of a straightened steel plate to flatten the surface, and then acetone is squirted on and the lap wiped with a cloth. The lap is then stopped, the abrasive mixture is thoroughly shaken, and about 5 cubic centimeters are poured onto the lap and spread over the entire surface of the lap with a dry hair-bristled brush, using a circular motion. For effective polishing the surface of the lap should be covered with a series of low, round-edged ridges of the abrasive mixture. To achieve this, brushing must not be continued after the abrasive becomes fairly sticky, as otherwise it will give sharp high ridges. A lap prepared in this manner gives a gentle but slow polishing action. For rougher action, the lap is first wetted with acetone, about 10 cc. of abrasive are added and worked with the brush until the abrasive is nearly dry. This gives sharp, higher ridges which cut much more rapidly. After the lap has been dressed it is permitted to run for about 5 minutes to thoroughly dry out the mixture. It normally requires about 8 minutes to re-dress the lap which then will polish, without further attention, for an hour at the normal rate of action, and much longer at a somewhat reduced rate of cutting. Specimens are run on the lap using the high pressure head with a pressure of about 6 pounds per specimen, but varied with the specimen. Whenever a lap is re-started it is wise to add first a few drops of dynamo oil and then dry the lap with a clean cloth. The purpose of this is to remove any debris which may have accumulated on the lap surface. The time required for this final polish varies between 10 minutes and an hour, or sometimes more, depending on the perfection of polish desired and the nature of the specimen.

During the polishing the specimens are periodically removed, washed with xylene, dried with absorbent paper and examined under the microscope to determine the progress of the polishing. It should be emphasized, however, that these laps require no alteration when running and that prolonged polishing will do no harm and may often greatly improve a surface. Mechanically these polishing units are practically fool-proof and the specimen cannot tip or jump off the lap. We commonly start a machine and let it run several hours without any attention, while working in another laboratory.

Laps prepared in the foregoing manner cut and polish at a rapid rate, as judged by the changes seen under the microscope. The actual rate of removal of material is of the order of .00005 inches per hour.

Although the foregoing description of the polishing process is given particularly with reference to the use of mechanical equipment, the

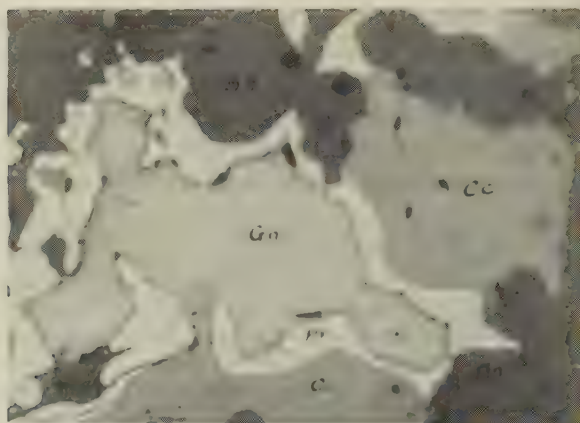


FIG. 7. Celotex polish. White, pyrite Py; light gray, galena Gn; medium gray, chalcocite Cc; darkest gray, bornite Bn. Mag. 150 diameters.



FIG. 8. Paper polish, same area as Fig. 7.

methods are wholly adaptable to hand work. The chief virtue of the mechanical equipment is to increase the number of specimens that can be handled at one time.

Figures 7, 8 and 9 give a comparative view of the same area when polished by the celotex, paper and cloth methods. It is interesting to note



not only the difference in relief but also the greatly increased visibility of minerals and textures as the quality of the polish is improved. Figure 10,

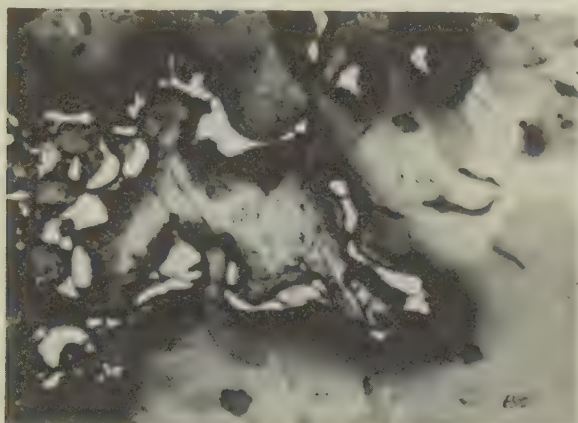


FIG. 9. Cloth lap polish, same area as Fig. 7.

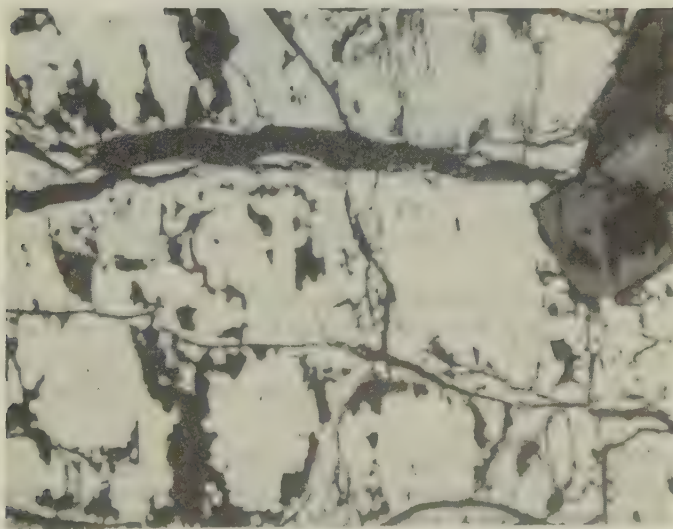


FIG. 10. Celotex polish. Pentlandite, white Pn; pyrrhotite, light gray Po; veined by silica, dark gray, and limonite in tiny veinlets. Mag. 55 diameters.

polished on celotex, shows an area of pyrrhotite and pentlandite veined by limonite and chalcedony stringers. Most of this detail can be seen only in a celotex or lead polish since the material is extremely friable and brittle.

## PAPER LAP POLISHING

The use of the paper lap polish is justified where one is willing to sacrifice somewhat the quality of the polish for the sake of much greater speed in obtaining the polish. The equipment necessary is simple and can be made in any machine shop in a comparatively short time. The abrasives used are obtainable commercially and do not require further sizing. The polish obtainable is good enough for many problems.



FIG. 11. Paper lap polishing equipment.

Specimens can be polished either mounted or unmounted. The flat surface is best obtained by sawing but can be made by grinding a chipped face. It is desirable to carry out the fine grinding on a bronze-lead lap. After a satisfactory matte surface is obtained, the final polishing is done dry on a paper lap as follows:

A sheet of Iroquois paper toweling, or paper of a similar structure, is spread over the lap and held in place by a spring metal ring which fits around the edge of the lap. Onto the lap surface is then spread a moderate quantity of abrasive which is rubbed in with a smooth, circular steel disk, pressed by hand against the lap while it is rotating. The lap is then started and a short period of running done with the steel disk after which it is ready for the specimen. The specimen is held on by hand using a moderate amount of pressure. It is rotated around its own axis and at the same time is moved back and forth from the edge to the center of the lap. We use an 8-inch horizontal iron lap which runs at approximately 1725 r.p.m. and is mounted directly onto a shaft of a ball-bearing motor as shown in Fig. 11. The average specimen requires from 5 to 20 minutes for the development of a scratch-free surface of moderate relief.



The method is faster than a celotex or lead lap and gives much less relief than a cloth lap. The paper is not strong enough to permit the use of a mechanical head. The method is entirely satisfactory for many types of ores. Other ores, however, are susceptible to the heat developed and oxidize sufficiently to materially affect the surface. Such specimens can often be improved by rubbing on a black rubber sheet such as is used as a floor sheet in automobiles. Figure 8 shows the relief developed in an ore whose mineralogy and texture form maximum relief. Figure 12 shows the polish attainable on an ore of more favorable texture.

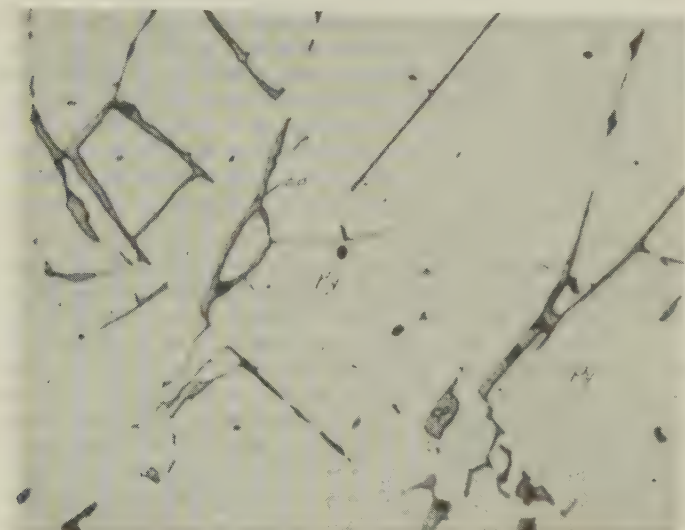


FIG. 12. Paper lap polish. Chalcopyrite veinlets (Cp) in pyrite (Py). Mag. 55 diameters.

### CONCLUSION

The development of a high quality polished surface is both physically and mechanically a much more difficult task than the preparation of a thin section of a rock. It is hoped that the foregoing concepts may aid in increasing the ease of preparing such sections and thus facilitate their general use.

Balch Graduate School of the Geological Sciences,  
California Institute of Technology,  
Pasadena, California.  
Contribution No. 328

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# THE MINERALOGY AND PARAGENESIS OF THE VARISCITE NODULES FROM NEAR FAIR- FIELD, UTAH. Part 1.

ESPER S. LARSEN, 3d,  
*Harvard University, Cambridge, Mass.\**

## ABSTRACT

The Fairfield variscite deposit is located about 50 miles south of Salt Lake City. The variscite occurs as nodules in a highly brecciated zone in limestone. The nodules are veined and surrounded by several other calcium aluminum phosphates; other rarer phosphate minerals are in cavities in the nodules. Miscellaneous additional data are given on some of the minerals. Weissenberg *x*-ray studies were made on wardite, deltaite, and gordonite. On the basis of *x*-ray powder photographs, wardite is shown to be related structurally and chemically to millisite, and deltaite to pseudowavellite.

The paragenetic relations of the minerals are described in detail. Variscite was deposited as nodules, and the other phosphate minerals are alteration and replacement products of the original variscite. The alteration history can be divided into four stages: In the first stage, quantitatively the most important, the bulk of the pseudowavellite was deposited with some deltaite, then millisite and wardite with some deltaite and lehiite, and finally more pseudowavellite and deltaite. The second stage comprises the crystal-forming minerals in cavities of variscite and pseudowavellite; these are, in their probable sequence, gordonite, englishite, montgomeryite, overite, and sterrettite. The third stage represents the deposition of a small amount of pseudowavellite, and the fourth, the deposition of the members of the apatite group. Each of these stages has characteristic chemical qualities.

The variscite was formed by phosphatic groundwaters descending along open fissures; the source of the phosphate was probably a phosphorite bed, weathering at the surface. The deposition of the variscite was probably caused by the reaction of aluminous material with the phosphatic waters. Later groundwater, no longer phosphatic, reacted with the variscite to form the alteration minerals. The different chemical characteristics of each group of alteration minerals reflect the changing composition of the groundwater which in turn was due to the weathering of varying surface materials.

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\* Contribution No. 251 from the Department of Mineralogy and Petrography, Harvard University.

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## INTRODUCTION

The descriptive mineralogy of the Fairfield variscite deposit has been known since the publication of Larsen and Shannon's paper (1930b) on the subject, but little has been written about the paragenetic relations of this or any other variscite deposit. Since the mineral assemblage at Fairfield is unique, so far as known, there is the logical assumption that the conditions of origin were perhaps also unique. An investigation of specimens from the deposit has been made with this in mind.

This study was undertaken at the suggestion of Professor Charles Palache, who had acquired a large new collection of Fairfield specimens for the Harvard Mineralogical Museum from Messrs. Arthur Montgomery and Edwin Over. The writer was fortunate in having this collection at his disposal. Moreover, Mr. Montgomery very generously furnished a large amount of additional material whenever it was needed.

The Fairfield variscite deposit has been known to mineral collectors for a number of years. The variscite is present as brilliant green nodules, which are veined and surrounded by bands of yellow, white, and gray alteration minerals. The nodules are found in a shattered and altered limestone (the "Great Blue" of Upper Mississippian age).

The deposit is located about 50 miles south of Salt Lake City in the southern end of the Oquirrh Range; more exactly, on the north slopes of Clay Canyon, five miles west of the town of Fairfield. It can be reached by a poor road from Fairfield.

The nodules were first discovered in 1893, and they were mentioned by Kunz (1895) in the Mineral Resources bulletin as a new type of occurrence for variscite. Other similar variscite deposits in Utah and Nevada have since been found. The Fairfield deposit was mined at the surface in a small way for a number of years, producing a considerable quantity of variscite suitable for semi-precious gems and ornamental stone. For the past twenty years or more the deposit has lain idle with the exception of sporadic mineral collecting. In 1937 the deposit was claimed by



Messrs. Montgomery and Over, who spent several months in 1937 and 1939 doing the first successful underground work. Their aim was to collect mineral specimens rather than gem material. The specimens used in this study comprised part of the material collected by them.

#### LITERATURE

The literature on the Fairfield deposit is very meagre. Kunz (1895) gave a very brief description of the deposit, and suggested the name "utahlite" for the gem variscite. Packard (1894) analyzed some of the material from one nodule and identified the green material as variscite. Wardite from Fairfield was described by Dennison in 1896. Sterrett (1905, '06, '07, '08, '09, '10) briefly described the deposit and the types of gem material produced. In 1930, Larsen and Shannon published the first detailed description of the mineralogy of the nodules, and recorded eight new minerals and the general occurrence of the minerals within the nodules. Pough has recently described the morphology of wardite (1937 *a*) and gordonite (1937 *b*). McConnell (1938) discussed lewistonite and dehrnite from Fairfield in their structural relation to other members of the apatite group. Gilluly (1932) described the geology of the Fairfield quadrangle but did not describe the variscite deposit.

#### PURPOSE AND METHODS OF THE STUDY

This investigation was undertaken, in part, to expand the known mineralogy of the deposit, and in part to consider the origin of the variscite and its alteration products. All the minerals were studied optically, and where suitable single crystals were available, their structural lattice was determined by the Weissenberg *x*-ray method. *X*-ray powder photographs were made of all the minerals observed and were used for purposes of identification and comparison. Thin sections were used to study some of the textural features. The spatial relations and the sequence of the minerals were studied more fruitfully in broken nodules under the binocular microscope. The work was carried out entirely in the laboratory; the field descriptions have been taken from the literature and from personal communications from Mr. Arthur Montgomery. The writer believes that further field investigation of this and other variscite deposits would be of value in testing the validity of some of the suggestions proposed in this paper.

#### ACKNOWLEDGMENTS

The principal collection of nodules used in this study was furnished by the Department of Mineralogy and Petrography of Harvard University, where the work was done. They also financed the chemical analyses and

the making of thin sections. Professor Charles Palache suggested the study and offered numerous valuable suggestions. Professor Esper S. Larsen gave valuable advice in the course of the work, and very kindly read and criticized the manuscript. Professor C. S. Hurlbut, likewise, read and criticized the manuscript. Drs. Wallace Richmond, Clifford Frondel, and C. W. Wolfe assisted greatly in the x-ray work. Dr. William T. Pecora contributed through many discussions.

I wish especially to thank Professor Harry Berman for his very constant interest in the work and his many criticisms, suggestions, and corrections, both in the course of the investigation and in the preparation of the manuscript.

Mr. Arthur Montgomery furnished unstintingly an abundance of material used throughout the study.

## GEOLOGY

### GENERAL GEOLOGY

Gilluly (1932) has described in detail the geology of the Fairfield quadrangle; the following brief description of the general geology of the area is taken from his publication and is summarized below.

The Fairfield quadrangle includes the southern end of the Oquirrh Mountains, the eastern extremity of the Basin and Range province. The rocks, dominantly Paleozoic sediments, are in a series of north-north-west trending open anticlines of variable dip. The stratigraphy is described in detail by Gilluly. The aggregate thickness of the Paleozoic strata is near 25,000 feet, dominantly limestones. These strata were compressed into the present anticlines at the end of the Paleozoic or early in the Tertiary. Following this, and in the Tertiary, there were extruded several thousand feet of latitic volcanics now found principally to the north; the same magma later rose toward the surface forming stocks, dikes, plugs, etc., with which the ore deposits of the area are associated. Considerable local faulting is attributed to the intrusions. Erosion during the Oligocene and early Miocene developed a "subdued mature surface" where the present mountains are located. From late Miocene or early Pliocene to the present, the Basin and Range faulting has tilted the Paleozoic strata to their present positions, which, together with accompanying erosion, has developed the present mountainous surface. Huge alluvial deposits have formed in the present valleys.

### GEOLOGY OF THE DEPOSIT

The variscite deposit lies on the east flank of the Ophir Anticline, the southernmost extension of the Oquirrh Mountains. It is located entirely in one sedimentary formation, the "Great Blue" limestone of Upper Mississippian age. Gilluly (1932, p. 29) has described this formation as follows:

"The 'Great Blue' limestone consists of a lower and an upper limestone, separated by shaly beds herein named the Long Trail shale member. The lower limestone member, between the top of the Humbug and the base of the Long Trail shale, is . . . about 500 feet thick . . . (The Long Trail member) is about 85 feet thick.



"Overlying the Long Trail shale is the upper limestone member of the 'Great Blue' limestone, consisting of blue-gray limestone like that beneath the shale and containing sporadic chert layers, some sandy limestone, and a very subordinate quantity of black shale . . . 2750 feet (is) the most probable thickness of the upper limestone member. . . .

"Other than the Long Trail shale member, no good marker beds were discovered in the 'Great Blue' limestone: it is a monotonous thick series of limestones throughout. In local areas, as at Mercur, individual thinner beds, mostly shales, were recognized in the formation . . . ."

The variscite occurs above the Long Trail shale member, but how far above is not known. The limestones have erratic dips and strikes in the neighborhood of the deposit, and at the deposit strike about N. 50° W. and dip 22° N. (Sterrett, 1908, p. 856).

No igneous rocks were mapped near Clay Canyon. Two miles northwest is a large rhyolitic plug (Eagle Hill) which may be genetically associated with the ore deposits near Mercur, farther to the north. There is no recurrence of intrusives south of Eagle Hill.

The structure of the deposit itself is only briefly recounted in the literature, and has been known only from surface workings. Kunz (1895, p. 602) wrote:

"The rock is a crystalline limestone, with layers of black pyritiferous slate. In the latter occur the nodules, varying from the size of a walnut to that of a cocoanut . . . ."

Sterrett (1908, p. 856) visited the deposit after the surface opening had been considerably developed, and wrote:

" . . . Development consists of a tunnel 110 feet long driven nearly north into the hill, and an open cut with a small incline. The tunnel did not cut the variscite lead. The country rock exposed in the workings is a black limestone, which strikes about N. 50° W., with a dip of 22° N. The variscite lead has a steeper dip to the north, nearly 45°, with approximately the same strike as the limestone. The variscite occurs in concretionary nodules in a brecciated, more or less decomposed, zone. Practically everything in this zone has a nodular shape, including the blocks of limestone breccia, etc. Chert forms a prominent part of the filling of the mineralized zone and has been fractured and cemented by calcite seams and limonite stains. The nodules of variscite range from one-fourth of an inch to over 4 inches in thickness. The nodules have been more or less fractured, and the cracks have been filled in with yellow and white phosphate minerals. Some of the larger nodules contain two or more smaller nodules or irregular masses of variscite, inclosed in yellow and white matrix or shells. Most of the nodules are surrounded by banded layers of the yellow phosphate and some have white coatings also."

Messrs. Montgomery and Over have recently done successful underground work on the deposit, and very kindly furnished data for the following more detailed description. Their work consisted of reopening a horizontal tunnel running into the hillside below the outcrop but which missed the mineralized zone (Sterrett, 1908). Lateral drifts from this tunnel struck the variscite area, and the zone of mineralization was followed from the lateral drift to the surface, a distance of about 100 feet.

The mineralized phosphate zone dips about  $25^{\circ}$  to the east, slightly steeper than the limestone, and the pitch of the zone is more northward than the true direction of dip of the limestone. The mineralized zone is one of extreme fracturing and brecciation, with several small through-going vertical faults, and small dip faults. The nodules are centered about vertical fractures, and generally occur along bedding fractures near the main vertical fractures. There are generally two, and locally three, well-defined phosphate streaks. These are discontinuous, and have a maximum vertical range of eight feet, and a lateral extent of about three feet. Where the mineralization is strongest, two or three main streaks may be close together, but separated by barren limestone, the whole having a width of ten feet or less. A few isolated patches or stringers of nodules were found away from the main fractures, but in diminished quantities. The nodules are found in masses of apparently altered limestone of which most is silicified or limonitized; as patches or layers parallel to the bedding surrounded by iron-stained earthy material; as angular fragments in brecciated limestone (silicified?); and as small nodules enclosed in angular alunite fragments. Many of the nodules are fractured and faulted, and a number of the bedding layers of nodules are offset, probably by late fracturing and small movements along them. The limestone in the mineralized area, and to some unknown distance away from it, is almost entirely silicified. Large cherty-appearing nodules and angular fragments of alunite are common. Late quartz and calcite were found in some of the fractures.

The amount of mineralization is considerably greater in the lower part of the workings, where the mineralized zone appears to expand. The nodular material at depth is completely altered to yellow pseudowavellite and a white mineral which may be pseudowavellite.

#### DESCRIPTIVE MINERALOGY

The minerals occurring in or associated with the nodules are discussed here from a strictly descriptive point of view; the details of their occurrence and sequence are considered in a later section. Each mineral found is described briefly; where new data have been gathered, they are given in detail. Morphological, structural, and chemical studies were made on suitable material if the data had not appeared in the literature. Three new phosphate minerals, overite, montgomeryite, and sterrettite, were found in the course of the study, and full descriptions of them are given elsewhere (Larsen, 1940; Larsen and Montgomery, 1940).

In all, fourteen species of phosphate minerals have been determined in the deposit; eleven were first described from this locality, and most of them are peculiar to it.

Following the scheme of classification of the phosphate minerals of Strunz and Schroeter (1939), the minerals in the Fairfield deposit fall in the following groups:

Group 1. Anhydrous phosphates without additional anions.

None.

Group 2. Anhydrous phosphates with additional anions.

Apatite group (lewistonite, dehrnite).

Group 3. Hydrous phosphates without additional anions.

Variscite . . . . .  $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$

Group 4. Hydrous phosphates with additional anions.

Pseudowavellite . . . . .  $\text{CaAl}_3(\text{PO}_4)_2(\text{OH})_6 \cdot \text{H}_2\text{O}$

Deltaite . . . . .  $\text{Ca}_2\text{Al}_2(\text{PO}_4)_2(\text{OH})_4 \cdot \text{H}_2\text{O}$

Dennisonite . . . . .  $\text{Ca}_3\text{Al}(\text{PO}_4)_2(\text{OH})_3 \cdot \text{H}_2\text{O}$

Wardite . . . . .  $\text{CaNa}_4\text{Al}_{12}(\text{PO}_4)_8(\text{OH})_{18} \cdot 6\text{H}_2\text{O}$

Millisite . . . . .  $\text{Ca}_2(\text{Na}, \text{K})_2\text{Al}_{12}(\text{PO}_4)_8(\text{OH})_{18} \cdot 6\text{H}_2\text{O}$

Lehiite . . . . .  $\text{Ca}_5\text{Na}_2\text{Al}_8(\text{PO}_4)_8(\text{OH})_{12} \cdot 6\text{H}_2\text{O}$

Gordonite . . . . .  $\text{MgAl}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 8\text{H}_2\text{O}$

Englishite . . . . .  $\text{Ca}_4\text{K}_2\text{Al}_8(\text{PO}_4)_8(\text{OH})_{18} \cdot 9\text{H}_2\text{O}$

Overite . . . . .  $\text{Ca}_3\text{Al}_8(\text{PO}_4)_8(\text{OH})_6 \cdot 15\text{H}_2\text{O}$

Montgomeryite . . . . .  $\text{Ca}_4\text{Al}_5(\text{PO}_4)_6(\text{OH})_5 \cdot 11\text{H}_2\text{O}$

Sterrettite . . . . .  $\text{Al}_6(\text{PO}_4)_4(\text{OH})_6 \cdot 5\text{H}_2\text{O}$

Overite was placed in Group 3 by Strunz and Schroeter on the basis of the tentative but incorrect formula  $\text{Ca}_3\text{Al}_6(\text{PO}_4)_8 \cdot 20\text{H}_2\text{O}$ , published by Larsen (1939).

Table 2 presents the chief properties of all the phosphate minerals found in the nodules.

#### VARISCITE— $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$ —orthorhombic

The identity of variscite has until recently been confused in the literature. Breithaupt (1830) described the mineral *peganite* and in 1837 described *variscite*. Moschetti (1917) and Schaller (1925) have shown that the two minerals are identical and that the original analyzed peganite probably contained some wavellite. The *callainite* of Dana may be variscite (Damour, 1865), although McConnell (1940) has lately questioned this. *Lucinite*, described by Schaller (1916) has been shown by Larsen and Schaller (1925) to be identical with variscite. Moreover, the euhe-dral material from Lucin, Utah, described by Schaller (1912 *a* & *b*) as variscite, has been shown by Larsen and Schaller (1925) not to be variscite but a new dimorphous form of  $\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$ , named by them *meta-variscite*; this error has not been fully recognized by Hintze (1931) in his description of the crystallography of variscite. The names *utahlite*, *chlorutahlite*, and *amatrice* have been used as trade names for gem variscite from Utah. All these names therefore represent but two species, variscite and metavariscite.

Variscite is isostructural with strengite (Schaller, 1912 *a* & *b*) and recent



studies (Strunz and Sztrókay, 1939; McConnell, 1939, 1940) have shown it to belong to the isodimorphous group including metavariscite, phosphosiderite, strengite, and others.

The variscite of the Fairfield deposit is a fine grained, massive, green aggregate, invariably in nodular form or as residuals in replaced or brecciated nodules. These nodules are the finest ever found and when polished make very handsome specimens. The color varies from a vivid emerald green to a lighter pea green. The colors are generally mottled over large areas, and the outer edges of the variscite masses in some nodules have a narrow line of darker green. Dark green lines of variscite, cutting massive variscite, can be seen on polished surfaces; this is probably a recrystallized variscite which has "healed" small incipient fractures.

A very minor amount of variscite is scattered through white powdery layers of a mineral related to pseudowavellite; Larsen and Shannon (1930 *b*) found this material to be in tiny crystals, coarser than the massive green mineral; the material studied by this writer was very fine grained and no crystals were found. Some of the white powdery layers have a faint greenish tinge on the surface facing the massive variscite, due to a concentration of loose variscite grains.

No crystals of variscite have been found at Fairfield, although the similar deposit at Lucin has yielded crystals (Schaller, 1915; Larsen and Schaller, 1925).

Two analyses of the Fairfield variscite have been published (Packard, 1894; Schaller, 1916); they both indicate a hydrous aluminum phosphate with some iron replacing aluminum. By analogy with strengite, the unit cell content of variscite is  $2(\text{AlPO}_4 \cdot 2\text{H}_2\text{O})$  (Strunz and Sztrókay, 1939; McConnell, 1940).

PSEUDOWAVELLITE— $\text{CaAl}_3(\text{PO}_4)_2(\text{OH})_5 \cdot \text{H}_2\text{O}$ —rhombohedral

DELTAITE— $\text{Ca}_2\text{Al}_2(\text{PO}_4)_2(\text{OH})_4 \cdot \text{H}_2\text{O}$ —rhombohedral

Pseudowavellite and deltaite are shown here to be isostructural and possibly isomorphous; for this reason they are discussed together.

Pseudowavellite was described by Laubmann (1922), and was identified as the dominant alteration mineral of the variscite at Fairfield by Larsen and Shannon (1930). It has been described from few localities, but there is little doubt that the mineral comprising the yellow crusts associated with variscite at the Utah and Nevada variscite deposits (see Sterrett, 1905, '06, '07, '08, '09, '10) is identical with the Fairfield pseudowavellite; specimens from Amatrice Hill, seen by the writer, contain pseudowavellite optically indistinguishable from the Fairfield material.

Deltaite was originally described from Fairfield by Larsen and Shannon (1930 *b*), and so far as is known to the writer has been found at no other locality.

Three types of occurrence of pseudowavellite were described by Larsen and Shannon. The most prominent mineral of the nodules is a yellow pseudowavellite forming successive layers on the outer parts of the nodules; this occurs as very fine fibers, either subparallel or matted, and having average indices of refraction  $\omega=1.618$ ,  $\epsilon=1.623$ . Vitreous crusts and veinlets, and spherules, ranging in color from yellow to gray, are made up chiefly of granular pseudowavellite ( $\omega=1.622$ ,  $\epsilon=1.631$ ) with some deltaite. White chalky crusts surrounding variscite are composed principally of pseudowavellite with indices  $\omega=1.619$ ,  $\epsilon=1.627$ ; this is very fine grained, in part either isotropic or so fine grained, as to appear so. Analyses of these three types are given by Larsen and Shannon (1930 *b*, Tables 2 and 3).

The same writers likewise describe three types of deltaite. As noted above, deltaite occurs intergrown with some vitreous pseudowavellite; this deltaite has indices  $\omega=1.641$ ,  $\epsilon=1.650$ , and in general has roughly euhedral outlines, apparently that of a trigonal prism, in very minute crystals. Gray cherty-looking crusts near variscite are made up of matted fine fibers of deltaite with indices  $\omega=1.630$ ,  $\epsilon=1.640$ . White chalky layers between the gray deltaite and the variscite kernels are considered to be deltaite by Larsen and Shannon; it is very similar optically to the white chalky pseudowavellite, and has indices  $\omega=1.621$ ,  $\epsilon=1.629$ , but is chemically somewhat different. This material was not seen by the writer, or else has been confused with the white chalky pseudowavellite. These three types of deltaite have been analyzed by Larsen and Shannon (1930 *b*, Table 4).

Three other types of deltaite have been seen by this writer. On one micromount are colorless minute crystals, apparently rhombohedra with a base, whose indices of refraction are  $\omega=1.640$ ,  $\epsilon=1.650$ . Very similar material, but canary yellow in color, occurs as sugary aggregates of very tiny crystals lining cavities in the nodules, chiefly in lenticular openings between pseudowavellite shells. These yellow crystals have a maximum dimension of 0.02 mm. and thus are far too small to study with the goniometer. Upon immersion under the microscope they are seen to be almost cubic in outline, but extinguish parallel to the face diagonals, suggesting that they are rhombohedra; rarely a corner is truncated by what is probably the base. This material has indices  $\omega=1.641$ ,  $\epsilon=1.651$ . A third type of deltaite comprises lavender colored trigonal prisms and massive aggregates of lavender to pale blue bands in a few of the nodules. This material has indices essentially identical with the types noted above. The

lavender crystals constitute the only deltaite suitable for crystallographic and x-ray Weissenberg study; the results of this study are given below.

X-ray powder photographs of the principal types of pseudowavellite and deltaite were taken, and they are all indistinguishable. It is assumed therefore that the minerals, including all their various types, are isostructural, and since the lattice spacings indicated by the photographs all appear to be very similar, it is assumed that the lattice dimensions of all the types are essentially identical.

#### *Lavender crystals of deltaite*

A few small nodules contain small lavender crystals of deltaite lining cavities in pseudowavellite. These crystals occur as single units and sub-parallel aggregates growing with the *c*-axis normal to the cavity walls. The aggregates are intermixed with fine aggregates of pseudowavellite. Radial groups of a mineral belonging to the apatite group perch upon crystals in the cavities. The lavender deltaite is uniaxial positive, with the indices of refraction:  $\omega = 1.640$ ,  $\epsilon = 1.651$ .

It has been impossible to prepare for chemical analysis a sample of the deltaite even moderately free from admixed pseudowavellite, since the densities of the two minerals are practically equal, preventing gravity separation, and the fineness of grain prohibits hand sorting.

The crystals of lavender deltaite are all simple, consisting of an elongated trigonal prism, terminated by the base. Their maximum dimension is near 0.2 mm. The base  $c\{0001\}$  reflects brilliantly, and on some of the crystals shows minute steps or striations parallel to the prism. The prism is rough with deeply grooved faces giving practically no reflections on the goniometer; a very weak train of reflections extends from the prism toward the base on some crystals. The prism, to fit the orientation chosen for the unit cell, is  $a\{10\bar{1}0\}$ .

The character and orientation of the unit cell were determined by the Weissenberg x-ray method. Rotation, and zero, first, and second layer Weissenberg photographs about  $[0001]$ , and rotation and zero layer Weissenberg photographs about  $[10\bar{1}0]$  were taken. From these were calculated the following unit cell dimensions:

For hexagonal lattice:

$$\left. \begin{array}{l} a_0 = 6.98 \text{ \AA} \\ c_0 = 16.10 \text{ \AA} \end{array} \right\} \pm 0.02 \text{ \AA}$$

$$a:c = 1:2.3066$$

$$V_0 = 679.3 \text{ cu. \AA}$$

$$M_0 = 1213 \text{ for } G = 2.95$$

For rhombohedral lattice:

$$a_{rh} = 6.71 \text{ \AA}$$

$$\alpha = 62^\circ 40'$$

$$V_{rh} = 226.3 \text{ cu. \AA}$$

$$M_{rh} = 405 \text{ for } G = 2.95$$



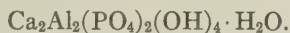
The space group is  $C_{3v}5-R3m$  as shown by the following observed reflections:

$$\begin{array}{l} \text{For } h\bar{k}l, h-k+l=3n \\ h\bar{h}2\bar{h}l, l=3n \\ h\bar{h}0l, 2h+l=3n \end{array}$$

The rhombohedral cell agrees with the apparent rhombohedral form of the colorless and yellow crystals of deltaite described above.

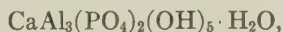
### *Chemical relationships*

Using the rhombohedral unit cell volume derived from the lavender crystals of deltaite, and the analysis of optically similar deltaite published by Larsen and Shannon (1930 *b*, Table 4, column 1), the calculated cell content of deltaite is close to:



Other available analyses of deltaite (Larsen and Shannon, 1930 *b*, Table 4) show an excess of Al and a deficiency of Ca over that required for the above formula.

Since *x*-ray powder photographs of deltaite and pseudowavellite show the two minerals to be isostructural and to have essentially identical cell dimensions, the rhombohedral cell volume determined for deltaite was used in calculating the unit cell content of pseudowavellite from the analyses given by Larsen and Shannon (1930 *b*, Tables 2 and 3). The cell content thus calculated closely approximates:



with an excess of Ca and a deficiency of Al in some.

The analyses of deltaite show a moderate deviation in composition from that expressed in the formula toward that of pseudowavellite, and the analyses of pseudowavellite show a similar deviation toward deltaite. The two minerals therefore seem to constitute an isomorphous series, at least partly miscible, in which one atom of Ca in deltaite can be exchanged for one atom of Al, with a consequent adjustment of the (OH) content to balance the valence change, to form pseudowavellite. The formula for the series can be written:



The formulae for the two minerals given by Larsen and Shannon do not suggest the isostructural character of the two minerals, or their apparent isomorphism.

WARDITE— $\text{CaNa}_4\text{Al}_{12}(\text{PO}_4)_8(\text{OH})_{18} \cdot 6\text{H}_2\text{O}$ —Tetragonal

Wardite was originally described by Dennison (1896) from Fairfield, Utah. Lacroix (1910) described the mineral soumansite from Montebbras, France, and this was shown by Larsen and Shannon (1930 *b*) to be identical with wardite. Larsen and Shannon analyzed the wardite from Fairfield and determined its physical and optical properties. Pough (1937 *a*) has described the morphology of the Fairfield wardite. Montebbras is the only occurrence of wardite mentioned in the literature outside of Utah; Zalinski (1909) and Pepperberg (1911) mention it as a probable constituent of the Amatrice Hill and Lucin variscite deposits.

Wardite at Fairfield occurs as subparallel aggregates of coarse fibers and aggregates and crusts of crystals, some individual grains exceeding one millimeter in diameter. They are most commonly blue-green, but grade to colorless. The crystals are tetragonal and characteristically pyramidal, terminated by the base. Most of the material is uniaxial positive, but some crystals are divided into four biaxial segments with a small  $2V$ ; this has been described by Lacroix (1910).

X-ray powder photographs of wardite and millisite are similar, indicating a close structural relationship; this is discussed in the section on millisite.

Rotation, and zero and first layer Weissenberg photographs about  $[001]$  and rotation and zero layer Weissenberg photographs about  $[110]$  were taken. The mineral proved to be tetragonal, as shown by Pough from the morphology, and has the following unit cell dimensions:

$$a_0 = 7.04 \text{ \AA}, c_0 = 18.88 \text{ \AA}, \text{ both } \pm 0.02 \text{ \AA}$$

The space group is  $C_42-P4_1$  or  $C_44-P4_3$  as shown by the observed reflections:

$$\begin{array}{l} \text{for } h00, h=2n \\ 0k0, k=2n \\ 00l, l=4n \\ \left. \begin{array}{l} h k 0 \\ h 0 l \\ h k l \end{array} \right\} \text{all present} \end{array}$$

The choice of axes agrees with that of Pough. The ratio of  $a_0:c_0=1:2.682$  indicates that Pough's choice of the  $c$ -unit is half the true unit; using Pough's morphological values,  $a:c=1:2.6234$ . These two values differ by three per cent, which is not surprising considering the poor quality of the crystals and the great range of Pough's measured values. The ratio derived by x-ray methods is probably better, and has been used in calculating the angle table (Table 1) for the forms observed by Pough. Included in the table are the measured mean values from Pough

(1937 *a*, Table 1). The form symbols have been changed to conform with the structurally determined units; the transformation is:

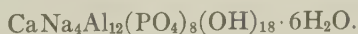
Pough to Larsen 100/010/002.

The dominant form *t*, given the symbol {13.0.12} by Pough, would become {13.0.24} with the present choice of unit, which is even less likely as a dominant form than with Pough's symbol. It seems most probable that this form should have the simple symbol *t*{102}; the  $\rho$  value of {102} by the new units is  $53^{\circ}17'$ , which is lower by twelve minutes than any of the measured  $\rho$  values given by Pough, but his measured range is greater than four degrees, indicating both poor and inconsistent faces. Form {907} of Pough seems more probably to be {203} in the new setting ({403} in the old); it is given as a doubtful form at best.

TABLE 1. WARDITE—ANGLE TABLE  
(Calculated from *x*-ray data)  
Tetragonal pyramidal?— $P4_{1-3}$   
 $p_0=2.6818$ ,  $a:c=1:2.6818$

Form	Symbol		Calculated		Measured Mean	
	Pough	X-ray	$\phi$	$\rho$	$\phi$	$\rho$
<i>c</i>	001	001	—	$0^{\circ}00'$	—	—
<i>a</i>	100	100	$0^{\circ}00'$	90 00	—	—
<i>t</i>	13.0.12	102	0 00	53 17	—	$54^{\circ}55'$
<i>u</i>	201	101	0 00	69 33	—	69 08
<i>b</i>	112	114	45 00	$43\ 28\frac{1}{2}$	$(45^{\circ}00'$	42 51)
Forms Requiring Confirmation						
	907	203	$0^{\circ}00'$	$60^{\circ}47'$	—	$59^{\circ}27'$
	301	302	0 00	76 04	—	74 56
	447	227	45 00	47 18	—	47 05
	134	138	18 26	46 40	$17^{\circ}44'$	45 27

The atomic content of the unit cell was calculated from the analysis of wardite published by Larsen and Shannon (1930 *b*, Table 1), and their value of the specific gravity 2.81, which new measurements by the writer checked closely. The unit cell contains



This differs from the formula for wardite given by Larsen and Shannon in having two less molecules of  $\text{H}_2\text{O}$ . The specific gravity calculated for this formula and the unit cell volume given above is 2.87, which compares poorly with the measured value 2.81.

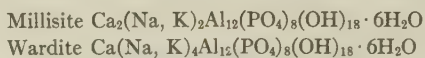


MILLISITE— $\text{Ca}_2(\text{Na}, \text{K})_2\text{Al}_{12}(\text{PO}_4)_8(\text{OH})_{18} \cdot 6\text{H}_2\text{O}$ —Tetragonal?

Millisite was described from Fairfield by Larsen and Shannon (1930 *b*), and this is the only known locality for the mineral.

Millisite is invariably associated with wardite as alternating layers in spherules or crusts. It is light gray to white in color, and normally is present as layers of fine fibers normal to the layering. No crystals of the mineral have been found. Where it coats crystals of wardite, it is not in crystallographic continuity, but is present as a thin shell with a fine-grained aggregate structure. Material sufficiently coarse indicates that it is biaxial positive with a moderate 2V, and indices of refraction slightly lower than wardite; fibers show negative elongation.

Millisite and wardite are very closely related chemically, as shown by the formulae:



in which potassium is very subordinate in wardite and is present in the approximate atomic ratio  $\text{Na}:\text{K}=2:1$  in millisite. X-ray powder photographs of the two minerals are similar and the principal spacings are nearly identical; thus the unit cell volume of wardite ( $V_0=936$  cu. Å) was used to calculate the probable unit cell content of millisite. The above formula indicates the probable cell content, assuming the measured specific gravity 2.83 from Larsen and Shannon. The calculated specific gravity for this formula is 2.87.

In all cases where the two minerals occur together (and they usually do) they are separate and distinct without any gradation from one to the other, and each maintains its separate properties. For this reason they are to be considered separate species and not necessarily members of a series.

LEHIITE— $\text{Ca}_5\text{Na}_2\text{Al}_8(\text{PO}_4)_8(\text{OH})_{12} \cdot 6\text{H}_2\text{O}$ 

Lehiite was described from Fairfield by Larsen and Shannon (1930 *b*) and this is the only known occurrence of the mineral. Material identified by this writer as lehiite differs somewhat from that described by Larsen and Shannon. It forms dense, light gray layers on the outer shells of the nodules, and is made up of fine to moderately coarse fibers generally in subparallel bands. It contains a few thin bands of coarse wardite. The original description of lehiite gives the optical properties:  $\alpha=1.600$ ,  $\beta=1.615$ ,  $\gamma=1.629$ , 2V large, optically negative, and a large extinction angle. The material seen by this writer was very finely fibrous with approximately parallel extinction; the fibers have negative elongation and the indices 1.605 parallel to the length, 1.620 normal to the length. It is too fine grained to determine its optical character. Although its opti-

cal properties do not coincide with those in the original description, its appearance and general range of indices of refraction suggest that it is lehiite. An x-ray powder photograph of this lehiite shows it to be unrelated to any of the other minerals found in the nodules. It is apparently not related chemically to any other known mineral.

DENNISONITE— $\text{Ca}_3\text{Al}(\text{PO}_4)_2(\text{OH})_3 \cdot \text{H}_2\text{O}$

Dennisonite, described from Fairfield by Larsen and Shannon (1930 *b*), was not found in the material studied by the present writer. The chemical formula suggests a relation to the pseudowavellite-deltaite series, such that one atom of Al in deltaite is replaced by one atom of Ca to form dennisonite; however, its optical properties are completely unrelated in any serial fashion with those of pseudowavellite and deltaite. It is said to occur in cavities in pseudowavellite and deltaite as fibrous, white botryoidal to spherulitic crusts.

GORDONITE— $\text{MgAl}_2(\text{PO}_4)_2(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ —Triclinic

Gordonite from Fairfield was described by Larsen and Shannon (1930 *b*) and related by them to paravauxite on the basis of chemistry and similarity in the interfacial angles of a few poor crystals. Pough (1937 *b*) described in detail the morphology and showed the morphological relation to paravauxite, the ferrous equivalent of gordonite.

It occurs most abundantly as prismatic triclinic crystals in bands of subparallel aggregates on or near variscite. It is most commonly smoky white to colorless; rare crystals are pale pink at their tips, or are pale green. Its prominent {010} cleavage and crystal form serve to distinguish it readily from the other minerals occurring with it.

The lattice constants of the unit cell were determined by x-ray methods. Rotation and zero layer Weissenberg photographs were taken about the three axes chosen by Pough, and a first layer Weissenberg was taken about [010]. Pough's setting and choice of units agree with the normal setting indicated by the x-ray study. The following are the lattice constants:

X-ray		Morphology (Pough)
$a_0 = 5.25 \text{ \AA}$	$\left. \begin{array}{l} b_0 = 10.49 \\ c_0 = 6.97 \end{array} \right\} \pm 0.02 \text{ \AA}$	
$b_0 = 10.49$		
$c_0 = 6.97$		
$\alpha = 107^\circ 20'$		$\alpha = 109^\circ 27'$
$\beta = 111^\circ 12'$		$\beta = 110^\circ 57\frac{1}{2}'$
$\gamma = 72^\circ 12'$		$\gamma = 71^\circ 40\frac{1}{2}'$
$\alpha^* = 77^\circ 49'$		$\lambda = 75^\circ 36'$
$\beta^* = 72^\circ 41'$		$\mu = 73^\circ 35'$
$\gamma^* = 102^\circ 52'$		$\nu = 102^\circ 49'$
$a_0:b_0:c_0 = 0.5004:1:0.6644$		$a:b:c = 0.5192:1:0.6942$
$V_0 = 332.7 \text{ cu. \AA}$		

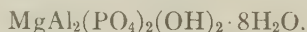
The crystals are apparently holohedral, so the probable space group is  $P\bar{1}-C_11$ .

The structural angles and ratios shown above are in poor agreement with the morphological angles and ratios determined by Pough. This is not unexpected when the uniformly poor quality of the crystals is considered.

The form  $S\{\bar{2}11\}$ , considered doubtful by Pough, was observed as a fairly large face reflecting a good signal on six crystals out of twelve measured by this writer, and should be considered well established. Below are given the measured range, the best average, and the calculated values for the  $\phi$  and  $\rho$  angles of this face:

Measured Range				Best Average		Calculated	
$\phi$		$\rho$		$\phi$	$\rho$	$\phi$	$\rho$
$-84^\circ 51'$	$-87^\circ 46'$	$65^\circ 43'$	$69^\circ 40'$	$-86^\circ 21'$	$68^\circ 04'$	$-86^\circ 02\frac{1}{2}'$	$68^\circ 06'$

The atomic content of the unit cell was calculated from the analysis of gordonite given by Larsen and Shannon (1930 *b*, p. 333), using the value of  $V_0$  given above and the specific gravity 2.23. The specific gravity was determined from seven small samples ( $2\frac{1}{2}$  to 7 mg.) of clear crystals on a microbalance; the average of these measurements was 2.23, as compared to Larsen and Shannon's value 2.28. The unit cell content is expressed by the formula given by Larsen and Shannon:



The calculated specific gravity of this is 2.22 for the above value of  $V_0$ .

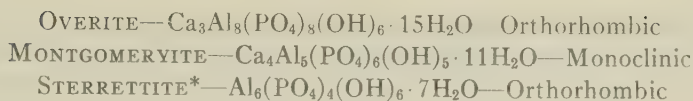
#### ENGLISHITE— $\text{Ca}_4\text{K}_2\text{Al}_8(\text{PO}_4)_8(\text{OH})_{10} \cdot 9\text{H}_2\text{O}$ —Monoclinic?

Englishite was described from Fairfield by Larsen and Shannon (1930 *b*) and has been noted from no other locality. It occurs as sub-parallel aggregates of flexible plates, and has a white pearly luster on its very perfect micaceous cleavage. It is found in cavities with wardite, and replacing variscite.

A Laue photograph was taken of a cleavage flake with the  $x$ -ray beam normal to the cleavage surface. The photograph was poor, due to the bent and aggregate nature of the cleavage flake, but showed a single plane of symmetry, indicating that the mineral is monoclinic. If the cleavage is considered the base, the optical orientation is:

$$Z=b, Y \text{ near } a, Z \text{ near } c.$$





These three new minerals were discovered in the course of this study and have been described recently in detail (Larsen, 1940; Larsen and Montgomery, 1940). Their chief properties are summarized in Table 2.

#### APATITE GROUP

Larsen and Shannon (pp. 324-327) described the two minerals, dehrnite and lewistonite, from the Fairfield nodules, and these have been shown by McConnell (1938) to belong to the apatite group. These minerals as described show considerable variation in their optical properties, and frequently have cores which are sharply distinct optically from the outer parts of crystals. They are found as hexagonal prisms, and subparallel aggregates of prisms; the crystals are commonly divided into six biaxial segments. In one type of dehrnite, the crystals show a uniaxial core surrounded by six biaxial segments; the core has the indices of refraction:  $\omega=1.640$ ,  $\epsilon=1.633$ , and the border:  $\alpha=1.585$ ,  $\gamma=1.600$ . Another type, considered to be dehrnite by Larsen and Shannon, occurs as botryoidal crusts in cavities in pseudowavellite and deltaite; these are made up of coarsely crystalline units, some divided into six segments, and are biaxial negative with a small 2V, and the indices of refraction  $\alpha=1.610$ ,  $\beta=1.619$ ,  $\gamma=1.620$ .

Lewistonite likewise shows wide variation in its properties. Stout hexagonal crystals associated with oolites of pseudowavellite are divided into six biaxial negative segments, with  $2V=42^\circ$ , and  $\alpha=1.613$ ,  $\beta=1.623$ ,  $\gamma=1.624$ . Some of these have uniaxial cores with  $\epsilon$  near 1.60. An amygdale is made up of stout fibers, apparently uniaxial negative, and  $\omega=1.621$ ,  $\epsilon=1.611$ .

Larsen and Shannon give the formula for dehrnite:  $14\text{CaO} \cdot 2(\text{Na}, \text{K})_2\text{O} \cdot 4\text{P}_2\text{O}_5 \cdot 3(\text{H}_2\text{O}, \text{CO}_2)$  and for lewistonite:  $15\text{CaO} \cdot (\text{K}, \text{Na})_2\text{O} \cdot 4\text{P}_2\text{O}_5 \cdot 8\text{H}_2\text{O}$ . Lewistonite contains less alkalis and considerably more water than dehrnite. Their optical properties overlap considerably so that it is impossible to distinguish between them.

Other members of the apatite group, as shown by x-ray powder photographs, are present in the nodules. These have not been studied chemically; optically  $\omega$  varies from 1.610 to 1.635.

The most abundant member of this group occurs as colorless crystalline aggregates and veinlets in pseudowavellite and chert fragments.

\* Sterrettite has very recently been shown to be identical with eggonite. Bannister, F. A., *Mineral. Mag.*, **26**, 131-133 (1941).

These aggregates are made up of stubby hexagonal prisms terminated by the unit pyramid; the crystals are rough and generally are sub-parallel groups rather than single individuals. Their optical properties are:  $2V(-) = 20^\circ$ ,  $\alpha = 1.622$ ,  $\gamma = 1.628$ ; negative elongation.

The apatite-like minerals are readily recognized as such after some experience. They are generally in recognizable hexagonal forms, and range from colorless to very pale green. They are the only hexagonal minerals found in the nodules. All colorless needle-like crystals or acicular sheaf-like aggregates seen in the nodules by this writer have been shown to be apatite members by x-ray methods. Besides these, all colorless to pale greenish spherules having finely botryoidal surfaces are likewise members of this group.

#### ALUNITE— $\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$ —Rhombohedral

Round nodules up to eight inches in diameter and angular fragments are made up of about two-thirds alunite and one-third quartz. They are creamy white to dark gray in color, and break with an even conchoidal fracture; they were originally thought to be chert nodules. They are very even grained, with the grain diameters of both the alunite and quartz averaging about 0.01 mm. The two minerals are uniformly inter-mixed.

Gently crushed fragments in immersion under the microscope show tiny rectangular grains which extinguish parallel to the grain diagonals; they have one index slightly higher than 1.570 and the other somewhat above 1.580. The grains are too small to give interference figures and thus the optical character is not known, but they are believed to be minute cleavage rhombohedra of alunite. The identification was confirmed by its chemical behavior. Heated in a closed tube it gives off acid water. Previous to ignition before the blow pipe it is insoluble in strong acids, but after ignition it is readily soluble in  $\text{HNO}_3$ . The solution in  $\text{HNO}_3$  gives a white precipitate when barium chloride is added, indicating  $\text{SO}_4$ ; it likewise gives a strong test for sulfur when reduced with charcoal and sodium carbonate. Broken surfaces are readily scratched by a needle, but its hardness appears high for alunite, probably due to the admixture of fine quartz.

#### OTHER MINERALS

*Quartz* is the most abundant mineral of the country rock, comprising strongly brecciated fragments of gray to black chert. Very tiny quartz seams cut the variscite nodules and are associated with pseudo-wavellite. Tiny quartz crystals coat the surfaces of some of the brecciated chert. On the outside surfaces of some of the variscite nodules, coarse quartz forms rounded milky aggregates.

TABLE 2. TABULATION OF COMPOSITIONS AND PROPERTIES OF THE MINERALS COMPRISING THE FAIRFIELD NODULES

Mineral	Cryst. Sys.	Ca	Na, K	Al	PO <sub>4</sub>	OH	H <sub>2</sub> O	Opt. Char.	$\alpha$	$\beta$	$\gamma$	2V	Sp. Gr.	H	Cleav.
Variscite	Orth.			8	8		16	Bi.—	1.569	1.586	1.594	large	2.52	5	
Pseudowavellite	Rhomb.	4		12	8	20	4	Un.+	1.619		1.628		2.92	5	
Deltaite	Rhomb.	8		8	8	16	4	Un.+	1.640		1.650		2.95	5	(0001)?
Wardite	Tet.	1	4	12	8	18	6	Un.+	1.590		1.599		2.81	5	(001)
Millisite	Tet.?	2	2	12	8	18	6	Bi.—	1.584	1.598	1.602	med.	2.83	5½	
Lehiite	Mon.?	5	2	8	8	12	4	Bi.—	1.602	1.616	1.629	large	2.89	5½	
Dennisonite	Hex.?	12		4	8	12	4	Un.—	1.591	1.601			2.85	4½	(0001)
Gordonite	Tri.	Mg 1		8	8	8	32	Bi.+	1.534	1.543	1.558	73°	2.23	3½	(010)
Englshite	Mon.?	4	2	8	8	10	9	Bi.—	1.570	1.572	1.572	small	2.65	3	(001)
Overite	Orth.	3		8	8	6	15	Bi.—	1.568	1.574	1.580	75°	2.53	5	mic.
Montgomeryite	Mon.	4		5	6	5	11	Bi.—	1.572	1.578	1.582	75°	2.53	5	(010)
Sterrettite	Orth.			12	8	12	10	Bi.—	1.572	1.584	1.601	60°	2.36	5	(010)
Dehrnite	Hex.?	12	4		8	4		Un.—	Range from 1.58 to 1.64				3.09	5	(110)
Lewistonite	Hex.?	15	2		8	8	4	Bi.—	1.613	1.623	1.624	42°	3.06	5	?
								Bi.—							(0001)



*Calcite* occurs principally as aggregates of coarse corroded crystals on the outer surfaces of a few variscite nodules; rarely it forms irregular masses on pseudowavellite inside a nodule. Much calcite, apparently original limestone, was seen in thin section surrounding a small nodule made up entirely of pseudowavellite; this calcite was almost opaque to transmitted light because of tiny inclusions of limonite (?). Most of the limonite contains abundant calcite, some in coarse grains.

*Limonite* is abundant as reddish to tan colored earthy material surrounding most of the nodules and commonly filling in between chert fragments. It is in large part incoherent and is mixed with varying amounts of very fine quartz. Some of the lighter colored earthy material may contain clay minerals.

Angular black fragments occurring enclosed in phosphate nodules are made up mostly of very fine grained quartz, but also contain evenly distributed tiny grains of an isotropic to weakly birefringent material, ranging in index from 1.58 to 1.62. It is insoluble in boiling  $\text{HNO}_3$  both before and after ignition, and thus is probably not a phosphate.

(To be continued)

# THE UNIT CELL AND SPACE GROUP OF ORPIMENT

M. J. BUERGER, *Massachusetts Institute of Technology.*

## ABSTRACT

An  $x$ -ray study of orpiment has been made using the equi-inclination Weissenberg method. The monoclinic character of this crystal is confirmed by  $x$ -ray evidence. The dimensions of the reduced cell are:

$$a = 11.47 \text{ \AA}$$

$$b = 9.57$$

$$c = 4.24$$

$$\beta = 90^\circ 27'.$$

This cell contains 4  $\text{As}_2\text{S}_3$ . Its axes have the same orientation as the morphological axes adopted by Mohs, Stevanović, Palache, and Modell, but the lengths of the axes are different. The matrix of the transformation from the Mohs-Stevanović-Palache-Modell axes to the Buerger axes is

$$\begin{vmatrix} 200 \\ 010 \\ 00\frac{2}{3} \end{vmatrix}$$

The space group of orpiment is unequivocally determined as  $P2_1/n$  ( $C_{2h}^5$ ) for this cell.

*Introduction:* Orpiment is one of the few remaining sulfide minerals of simple composition for which there are no published  $x$ -ray crystallographic data. The reason for this is evidently that the crystals are so very plastic that it is difficult to obtain a single crystal which has not been bent or otherwise deformed in the process of removing it for study. The writer was fortunate in obtaining an excellent crystal of orpiment (from Mercur, Utah) from Dr. Harry Berman, who skillfully detached it from a protected cavity in a large specimen. While the point of attachment of the crystal had been injured, it retained a perfect, undistorted termination.

Orpiment, formerly believed to be orthorhombic,<sup>1</sup> is now regarded as monoclinic. The lower symmetry has been confirmed by studies and measurements of morphological development,<sup>2,3</sup> by the results of etching experiments,<sup>2</sup> and by optical observations.<sup>3</sup> Nevertheless, the departures of both angular and optical measurements from orthorhombic character are so slight that the results of an  $x$ -ray crystallographic study are of considerable interest.

*Method:* A somewhat elongated crystal having a single perfect termination can only be rotated about its axis of elongation if the distorted part is to be kept out of the  $x$ -ray beam. For this reason, a set of equi-

<sup>1</sup> Mohs, Friedrich (translated by William Haidinger), *Treatise on Mineralogy* (Archibald Constable and Co., Edinburgh, 1925), vol. 3, pp. 47-49.

<sup>2</sup> Stevanović, S., Auripigment von Allchar in Macedonien: *Zeits. Krist.*, **39**, 14-18 (1904).

<sup>3</sup> Palache, Charles, and Modell, David, Crystallography of stibnite and orpiment from Manhattan, Nevada: *Am. Mineral.*, **15** (1930) especially 371-374.

inclination Weissenberg photographs was taken with the orpiment crystal for rotations about the  $c$ -axis only. The length of the  $c$ -axis permitted taking zero, first, second, and third level photographs with copper radiation.

*Symmetry:* The symmetry of the zero level Weissenberg photograph is  $C_{21}$ , while the symmetry of each of the several  $n$ -levels is  $C_1$  (see Fig. 1). This is consistent with a monoclinic character of orpiment, but is inconsistent with an orthorhombic character. The inferior symmetry of the  $n$ -levels is displayed only by the intensities of the spots on the film; the position symmetry of the spots on the  $n$ -levels is so close to  $C_{21}$  that a departure from this position symmetry can be detected only by refined measurements.

*Unit Cell:* Inspection of the several  $c$ -axis Weissenberg photographs revealed the facts that the patterns of the several reciprocal lattice levels normal to  $c$  are identical, and that furthermore the cell types are rectangular. This indicates<sup>4</sup> that orpiment is based upon a primitive lattice.

The length of the  $c$ -axis was measured from the layer spacings of a rotation photograph. Each of two levels gave a value of 4.24 Å. These consistent results were obtained by placing the undeformed tip of the tiny crystal in the center of the beam, and then making layer line spacing measurements from tip to tip of the resulting reflections.

The  $a^*$  and  $b^*$  translations for the reduced reciprocal cell were determined by making  $x$ -measurements of the pinacoid reflections on the  $c$ -axis, zero layer photograph. These values were refined by extrapolation according to the method of Bradley and Jay.<sup>5</sup> Utilizing the refined value of  $b^*$  as found by this method, the crystallographic angle,  $\beta$ , was found by the method of dome offsets.<sup>6</sup> These several measurements establish the following reduced, simple monoclinic cell:

	ratio
$a = 11.47 \text{ Å}$	1.195
$b = 9.57$	1
$c = 4.24$	.442
$\beta = 90^\circ 27'$	

<sup>4</sup> Buerger, M. J., The application of plane groups to the interpretation of Weissenberg photographs: *Zeits. Krist.*, (A) **91** (1935) especially 257-264.

<sup>5</sup> Bradley, A. J., and Jay A. H., A method for deducing accurate values of the lattice spacing from x-ray powder photographs taken by the Debye-Scherrer method: *Proc. Phys. Soc.*, **44**, 563-579 (1932).

<sup>6</sup> Buerger, M. J., The x-ray determination of lattice constants and axial ratios of crystals belonging to the oblique systems: *Am. Mineral.*, **22** (1937), especially 425-428.



It is known that the axes recorded above correspond in orientation with the axes of Palache and Modell, who adopted Stevanović's axial

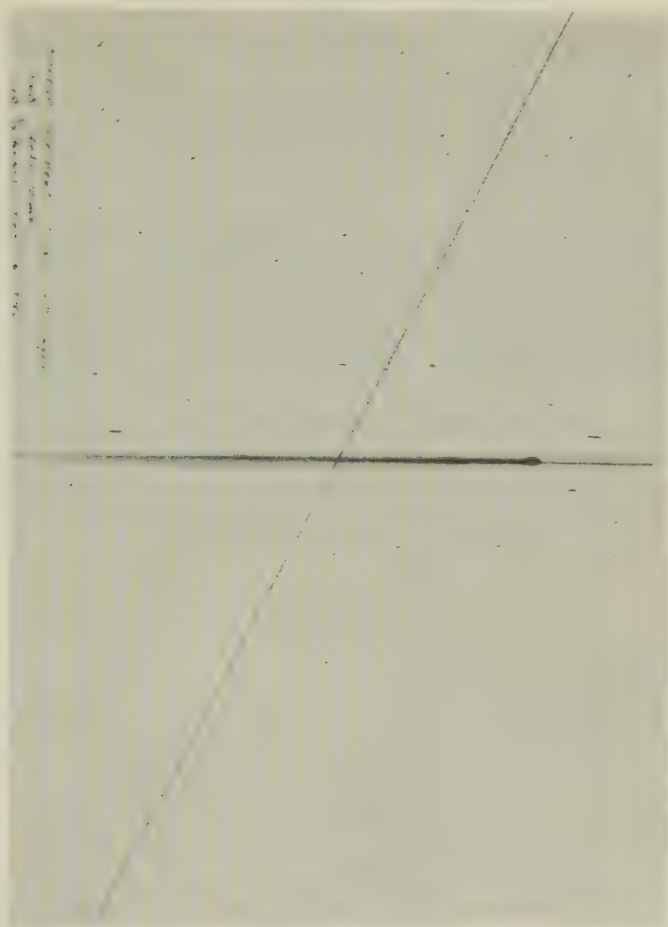


FIG. 1. Equi-inclination Weissenberg photograph of orpiment;  $c$ -axis, 2nd level, copper radiation. The only symmetry displayed by the photograph is the line shown, indicating the symmetry  $C_1$  for the level.

ratio. This ratio, and the new one determined by  $x$ -ray methods compare as follows:

	Stevanović	relation	Buerger
$a$	.5962	$(\times 2 = 1.1928)$	1.195
$b$	1		1
$c$	.6650	$(\times \frac{2}{3} = .4421)$	.442

Accordingly the matrix of the transformation from the axes of Stevanović to those of Buerger is

$$\begin{vmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \frac{1}{2} \end{vmatrix}$$

Stevanović determined the density of the orpiment from Allchar, Macedonia as 3.49. Using this value, the orpiment cell contains 4  $\text{As}_2\text{S}_3$ . For the cell constants given above, the computed value of the density is 3.48.

*Space Group:* The  $c$ -axis, zero level Weissenberg photograph displays doubled reciprocal cell translations along the central  $[010]^*$  line. Comparison of the photographs of the several levels shows that the only other systematic multiple translations of the reciprocal lattice are all the  $[101]^*$  translations in central  $(010)^*$ . These two conditions indicate respectively a two-fold screw axis  $\parallel b$  and a diagonal glide  $\parallel (010)$ . Taking into account the symmetry discussed above, the space group is unequivocally determined as  $P2_1/n$  ( $C_{2h}^5$ ).

# BIXBYITE AND PSEUDOBROOKITE FROM THE TIN-BEARING RHYOLITE OF THE BLACK RANGE, NEW MEXICO\*

CARL FRIES, JR., WALDEMAR T. SCHALLER, AND JEWELL J. GLASS,  
*Geological Survey, Washington, D. C.*

## ABSTRACT

Bixbyite,  $(\text{Mn}, \text{Fe})_2\text{O}_3$ , has been found at five localities in the tin-bearing rhyolite in the Black Range in southwestern New Mexico. It occurs as small cubes implanted with specularite and cassiterite on fissure walls and in cavities and lithophysae with topaz, quartz, specularite, and opal. Two new forms,  $u\{554\}$  and  $t\{421\}$ , were found. A review of chemical analyses reported for bixbyite and a new analysis of material from the Black Range substantiates the formula  $(\text{Mn}''', \text{Fe}''')_2\text{O}_3$ . This is the third verified occurrence for the mineral.

Pseudobrookite,  $\text{Fe}_2\text{O}_3 \cdot \text{TiO}_2$ , occurs in cavities widely distributed throughout the tin-bearing rhyolite. Crystals collected from one of the bixbyite localities show six new prism forms,  $d\{560\}$ ,  $f\{11.10.0\}$ ,  $g\{650\}$ ,  $i\{320\}$ ,  $j\{830\}$ , and  $k\{410\}$ . This is the third recorded occurrence in the United States.

A review of the occurrences for bixbyite and for pseudobrookite indicates that the minerals have not been found as pyrogenetic accessories. Their origin has been attributed only to fumarolic or pneumatolytic processes. It is reasonable to attribute the origin of these minerals in the tin-bearing rhyolite of the Black Range to vapors escaping from the cooling flows.

## INTRODUCTION

Small glossy black cubes of bixbyite and tiny slightly radiating groups of crystals of pseudobrookite were found in the tin-bearing rhyolite of the Black Range in Sierra and Catron counties, New Mexico, during an investigation of the tin deposits under the Strategic Minerals Act in the fall of 1939 and in the summer and fall of 1940. The identity of the bixbyite was not suspected until fragments of the mineral were observed by one of the authors (J. J. G.) in heavy concentrates during laboratory studies at the Federal Geological Survey. More than 2000 crystals ranging in size from 0.5 mm. to about 6 mm. on the edge were collected. Specimens of pseudobrookite were collected from only one locality.

## GEOLOGY

The tin-bearing rhyolite in the Black Range forms relatively undeformed flows of Tertiary age. It is in general coarsely porphyritic and contains from 20 to 40 per cent phenocrysts, which are largely sodasanidine and quartz. Minor quantities of oligoclase and biotite are pres-

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ent. The groundmass is made up of microcrystalline quartz and feldspar and is slightly to very vesicular throughout the greater part of the areas where the rhyolite crops out. Minerals present in these vesicles in different parts of the region include magnetite, specularite, bixbyite, pseudobrookite, sphene, andradite garnet, topaz (high fluorine-low water type), quartz, sanidine, cristobalite, tridymite, chalcedony, opal, zeolites, fluorite, and calcite. The walls of some of the narrow irregular fissures in a dozen small areas in the rhyolite are incrustated largely with specularite and cassiterite, but all the minerals of the vesicles, except pseudobrookite, sphene, and topaz, have been found in one or more of the incrustations. A somewhat more detailed description of the geology is given by Fries.<sup>1</sup>

#### BIXBYITE, (Mn, Fe)<sub>2</sub>O<sub>3</sub>

*Occurrence and association.*—Bixbyite was first discovered in the Thomas Range in Utah and was described by Penfield and Foote<sup>2</sup> in 1897. The second discovery of the mineral was made in Valle de las Plumas, northern Patagonia, in 1923. A handwritten report, dated 1930, of a study made by Sarah Cortelezzi de Mouzo on 6 crystals from that locality is on file in the Museum of La Plata, Buenos Aires. Schiller<sup>3</sup> gave an abstract of her paper in 1931. A chemical study was made by Corti<sup>4</sup> in the same year. A more detailed crystallographic study was later made by Cortelezzi, Himmel, and Schroeder<sup>5</sup> on a collection of 50 crystals. Bixbyite is also mentioned, but with unconfirmed identity, in a list of minerals from a locality in Spain.<sup>6</sup>

The bixbyite from the Black Range does not occur throughout all the rhyolite but appears to be limited to small areas. It is present in and within 2 feet of a narrow fissure filled with specularite and cassiterite in a small prospect trench 300 yards southeast of the road from Beaverhead to Winston, in the center of the south half of section 22, T. 10 S., R. 11 W. The largest crystals found (see Fig. 1, a and b) are in lithophysae, together with specularite, quartz, and opal, in the rhyolite along-

<sup>1</sup> Fries, Carl, Jr., Tin deposits of the Black Range, Catron and Sierra Counties, New Mexico; a preliminary report: *U. S. Geol. Survey, Bull.* **922-M**, 360-365 (1940).

<sup>2</sup> Penfield, S. L., and Foote, H. W., On bixbyite, a new mineral, and notes on the associated topaz: *Am. Jour. Sci.*, 4th ser., **4**, 105-110 (1897).

<sup>3</sup> Schiller, W., Abstr. La Existencia de la Bixbyita en la Patagonia, by Sarah Cortelezzi de Muzzo, 20 handwritten pages: *Neues Jahrb. Min.*, Referate **1**, 133-135 (1931).

<sup>4</sup> Corti, Hércules, Datos sobre una nueva variedad de bixbyita hallada en el Chubut: *Anal. Asoc. Quim. Argentina*, **19**, 109-116 (1931).

<sup>5</sup> Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert, Bixbyit von Patagonien: *Centralbl. Mineral., Geol., u. Paleon.*, Ab. A, 129-135 (1934).

<sup>6</sup> Tomás, Llorenç, Els minerals de Catalunya: *Treballs Inst. Catalana Hist. Nat.*, 246, vol. for 1919-1920.

side the incrustated fissure walls. Other crystals, such as those shown in Fig. 1, c, are intergrown with specularite and cassiterite in the incrustation, or implanted with specularite, quartz, and sanidine on the walls of cross fissures. The pseudobrookite that is described is present in lithophysae about 50 feet west of the incrustation.

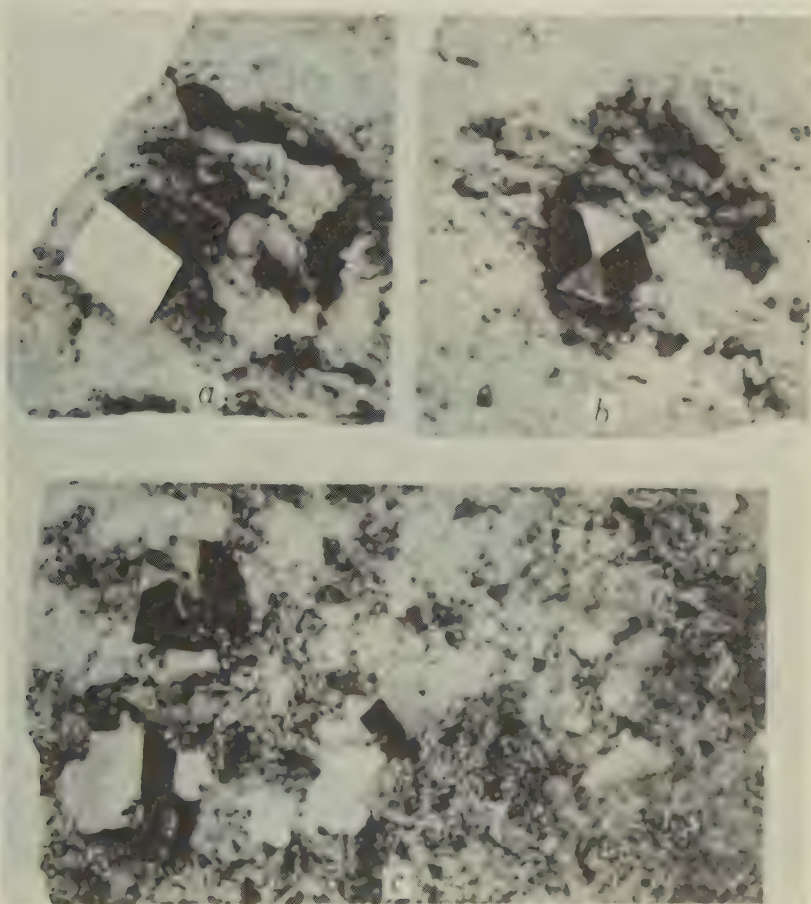


FIG. 1

- a. Cube of bixbyite in lithophysa. The shell-like cavity also contains many tiny clear crystals of quartz.  $\times 2$
- b. Crystal of bixbyite showing combination of cube and octahedron in a vesicle with quartz and hyaline opal.  $\times 2$
- c. Cubes of bixbyite on wall of fissure. Clusters of small crystals of cassiterite are attached to the sides and edges of the bixbyite. Thin black plates are specularite, white crystals are sanidine; and glassy transparent crystals are quartz.  $\times 2$

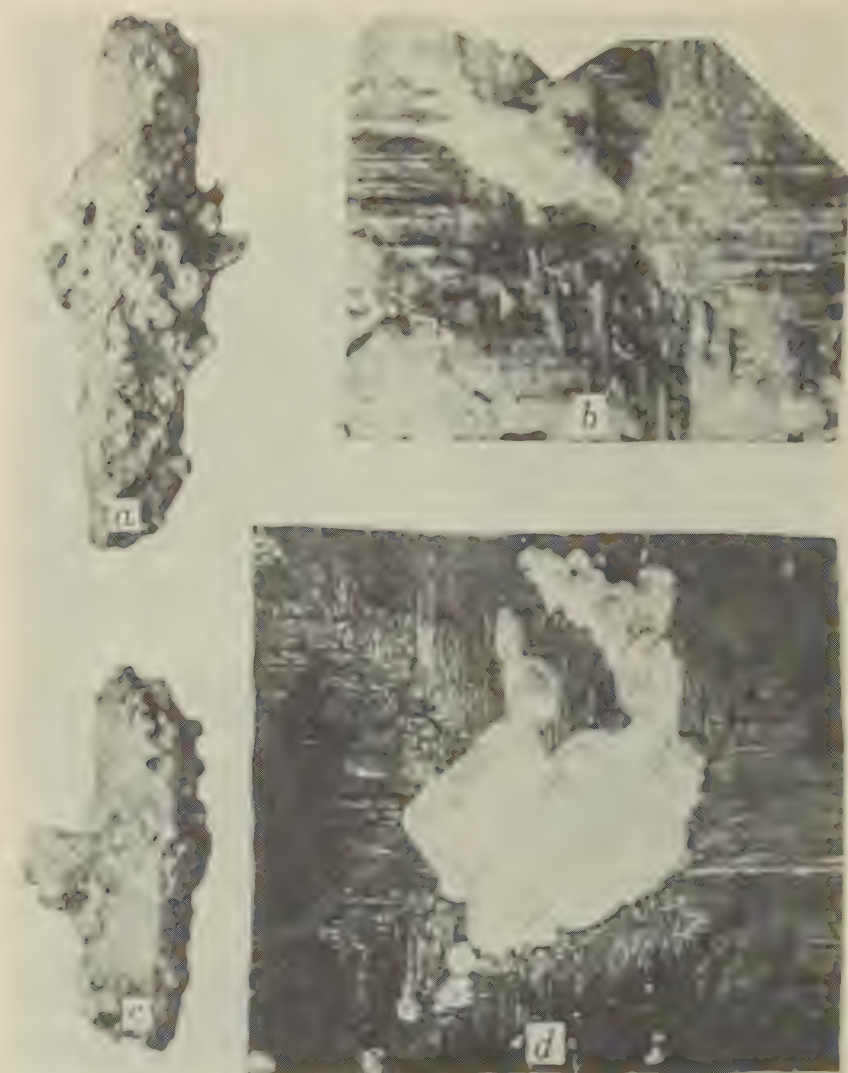


FIG. 2

- a and c. Crystals of topaz incrustated with quartz, specularite, and bixbyite.  $\times 2$   
 b. Cube face of bixbyite crystal showing pattern of markings present on many crystals.  
 $\times 20$   
 d. Similar to b, except that markings are finer. Light patch near center is unstriated.  
 $\times 3$



A few crystals of bixbyite were found in a small shaft sunk on a veinlet of specularite and cassiterite 200 yards north of Hardcastle Creek, in the NW $\frac{1}{2}$  of the NE $\frac{1}{4}$  of section 4, T. 10 S., R. 10 W. They are intergrown with specularite in the veinlet.

The larger part of the bixbyite was collected from a small prospect pit 200 yards northeast of Scales Creek, in the NW $\frac{1}{4}$  of the NW $\frac{1}{4}$  of section 31, T. 10 S., R. 10 W. The highly friable white rhyolite within one foot of a small veinlet of specularite carries an abundance of small, nearly perfect cubes and clusters of as many as 6 interpenetrating cubes. Recovery of the bixbyite is possible by disintegrating and panning the friable rock. Some of the crystals are intergrown with specularite in the veinlet. Bixbyite is implanted with specularite and quartz on the walls of a narrow fissure in a small prospect pit 400 yards north of this and 400 yards northeast of Scales Creek, in the SW $\frac{1}{4}$  of the SW $\frac{1}{4}$  of section 30, T. 10 S., R. 10 W.

A fourth locality is at the west base of Round Mountain, also known as Maverick Mountain, 1300 yards north of Main Diamond Creek, in section 30, T. 11 S., R. 10 W. The rhyolite at this place contains numerous cavities, in some of which occur crystals of topaz up to an inch in length. Tiny crystals of bixbyite, specularite, and quartz incrust the large crystals of topaz, as illustrated by Fig. 2, a and b. No definite orientation of the bixbyite was noted, such as that described by Pabst<sup>7</sup> on material from Utah. The bixbyite crystals range from half a millimeter to 2 or 3 mm. in diameter. A thin film of hyaline opal covers parts of some of these aggregates.

Heavy mineral concentrates of rhyolite taken from a prospect adit driven in 1939 by the Federal Bureau of Mines, in the NW $\frac{1}{4}$  of the SW $\frac{1}{4}$  of section 2, T. 11 S., R. 12 W., contain broken fragments of bixbyite, though the mineral was not recognized in hand specimen. The rhyolite at this place is porous and friable and is cut by numerous fissures, the walls of some of which are incrustated with specularite and cassiterite.

There seems little doubt but that detailed search of the tin-bearing rhyolite in the region would lead to the discovery of additional areas in which bixbyite is present.

A summary of the occurrences of bixbyite and the associated minerals in the 3 localities known, New Mexico, Utah, and Patagonia, is given in Table 1.

<sup>7</sup> Pabst, Adolph, Orientation of bixbyite on topaz: *Am. Mineral.*, **23**, 342-347 (1938).

TABLE 1. OCCURRENCES OF BIXBYITE AND ASSOCIATED MINERALS

Locality	1. New Mexico	2. Utah	3. Patagonia
Enclosing rock	Rhyolite	Rhyolite	Trachyte?
Where present	In cavities and in- crustations	In cavities	In veins?
Minerals found in contact with bixbyite	Specularite Topaz Cassiterite Quartz	Specularite Topaz Spessartite? Garnet Quartz	Quartz  ?
Minerals not found in con- tact with bixbyite, but present in cavities; associ- ation inferred	Pseudobrookite Magnetite Andradite garnet Sphene Sanidine Cristobalite Tridymite Chalcedony Opal Zeolites Fluorite Calcite	Pseudobrookite Beryl Fluorite Calcite	?

1. Tin-bearing rhyolite of the Black Range, New Mexico.
2. The Thomas Range, Utah. See Montgomery, Arthur, A recent find of bixbyite and associated minerals in the Thomas Range, Utah: *Am. Mineral.*, 19, 82-87 (1934). See also Palache, Charles, Minerals from Topaz Mt., Utah: *Am. Mineral.*, 19, 14-15 (1934).
3. Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert: *op. cit.*, p. 29.

The similarity of the occurrences in New Mexico and in Utah is apparent. The presence of bixbyite in the cassiterite-bearing incrustations in New Mexico may be significant in interpreting the environment in which the tin was deposited. The shorter list of associated minerals in the Utah occurrence may be due to a less complete study of the rhyolite, as at least one or more of the other silica minerals would be expected in the vesicles. The bixbyite from Patagonia is reported to be in a brecciated quartz vein which cuts a trachyte with well developed flow structure. The trachyte has a fine-grained or glassy groundmass and phenocrysts of quartz, plagioclase, orthoclase, biotite, ilmenite, and hematite. Quartz is the only mineral mentioned that is associated with bixbyite. Flows of rhyolite are near the bixbyite occurrence, it is said.

*Crystallography.*—The forms<sup>8</sup> present are  $a\{100\}$ ,  $d\{110\}$ ,  $o\{111\}$ ,  $n\{211\}$ ,  $u\{554\}$ , and  $t\{421\}$ , the last two forms being new for bixbyite.

Out of about 2000 crystals examined, 57 or about 3 per cent show the combination  $a\{100\}$ ,  $o\{111\}$ , and 36 or about 2 per cent show the combination  $a$ ,  $o$ ,  $n\{211\}$ . Six crystals were selected and carefully measured. Crystal no. 4 showed one very small face of  $d\{011\}$ , first noted on crystals from Patagonia, and two faces of the new form  $u\{554\}$ , as well as  $a$ ,  $o$ , and  $n$ . On crystal no. 6, with  $a$  and  $o$ , 13 faces of the new form  $t\{421\}$  were measured. No faces of  $n\{211\}$  were seen on this crystal. No faces of  $x\{321\}$  were observed on any of the crystals from New Mexico, although this form is present on 10 of the 50 crystals from Patagonia, described by Cortelezzi, Himmel, and Schroeder.

TABLE 2. MEASUREMENTS OF  $u\{554\}$  ON BIXBYITE FROM NEW MEXICO

Angle	$\phi$	$\rho$
Measured	44°56'	60°32'
	45°09'	60°24'
Calculated	45°00'	60°30'

TABLE 3. MEASUREMENTS OF  $t\{421\}$  ON BIXBYITE FROM NEW MEXICO

Face	(142)		(214)		(241)	
Angle	$\phi$	$\rho$	$\phi$	$\rho$	$\phi$	$\rho$
Measured	13°38'	63°29'	27°38'	28°54'	26°37'	77°29'
	13 37	63 48	26 57	29 08	26 31	77 17
	14 13	64 06	26 12	29 02	26 45	76 04
	13 38	64 05	26 34	30 16	27 45	75 07
			27 51	29 57		
Average	13 47	63 52	27 00	29 27	26 55	76 29
Calculated	14 02	64 07	26 34	29 12	26 34	77 23

Only a single very small face of  $d\{011\}$  was observed. It measured:  $\phi=0^\circ31'$ ,  $\rho=45^\circ03'$ .

<sup>8</sup> In their description of the crystals from Patagonia, Cortelezzi, Himmel, and Schroeder use the letters advocated by Goldschmidt, namely  $c$  for  $\{100\}$ ,  $p$  for  $\{111\}$ ,  $q$  for  $\{121\}$ , and  $x$  for  $\{321\}$ . The letters used by Dana are used in this paper, except for  $\{321\}$  where priority of discovery extends them the privilege of assigning their choice. Penfield used  $a$  for  $\{100\}$  and  $n$  for  $\{211\}$ , and Montgomery used  $o$  for  $\{111\}$ .

The two measurements of the new form  $u\{554\}$  are given in table 2.

The first face of  $\{554\}$  was small but as large as the small faces of  $\{111\}$ , whereas the second face of  $\{554\}$  was very small. Both faces gave poor reflections.

The faces of the new form  $t\{421\}$  were all small and somewhat striated. The crystal on which they occur has large faces of  $a\{100\}$ , with medium-sized faces of  $o\{111\}$ , much broken up. The measurements of  $t\{421\}$  are given in Table 3.

TABLE 4. FIRST DESCRIBED OCCURRENCE OF CRYSTAL FORMS OF BIXBYITE

Forms	First described occurrence			Combinations			
	Utah	Patagonia	New Mexico	Utah		Patagonia	New Mexico
				P. & F.	M.		
$a\{100\}$	P. & F., 1897	—	—	$a$	$a$	$a$	$a$
$d\{110\}$	—	C., 1931	—	—	—	$d$	$d$
$o\{111\}$	—	C., 1931	—	—	$o$	$o$	$o$
$n\{211\}$	P. & F., 1897	—	—	$n$	$n$	$n$	$n$
$u\{554\}$	—	—	P.p.	—	—	—	$u$
$x\{321\}$	—	C.H. & S., 1934	—	—	—	$x$	—
$t\{421\}$	—	—	P.p.	—	—	—	$t$

P. & F., 1897. Penfield, S. L., and Foote, H. W.: *Op. cit.*, p. 105.

C., 1931. Corti, Hércules: *Op. cit.*, p. 111. Corti presents a drawing indicating also the forms  $\{221\}$  and  $\{265\}$  but gives no measurements.

C.H. & S., 1934. Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert: *Op. cit.*, pp. 129–135.

P.p. Present paper.

M. Montgomery, Arthur: *Op. cit.*, p. 83.

Most of the crystals from both Utah and New Mexico are simple cubes. Penfield and Foote described bixbyite from Utah as crystallizing “usually in cubes,” and Montgomery says: “Practically all the crystals are simple cubes. . . .” About 95 per cent of the 2000 crystals from New Mexico likewise are simple cubes. All the 50 measured crystals from Patagonia show  $a$  and  $n$ , and 60 per cent of the crystals also have  $d\{110\}$ ; 20 per cent have  $x\{321\}$ , and 4 per cent have  $o\{111\}$ .

The faces of the cube on the crystals from New Mexico are usually striated, as already described on crystals from Patagonia by Cortelezzi, Himmel, and Schroeder,<sup>9</sup> and many are uneven and irregular. (See Fig. 2, b and d.) On the most deeply furrowed crystals the two parts in one

<sup>9</sup> Cortelezzi, Juana, Himmel, Hans, and Schroeder, Robert: *Op. cit.*, pp. 129–135.



zone are inclined from  $11^{\circ}$  to  $12^{\circ}$  to the cube face, the striations approaching the form  $\{150\}$  (with  $\phi$  angle of  $11^{\circ} 19'$ ). On other crystals the striations are inclined only about  $7^{\circ}$  to the cube.

The relative size of the faces of  $o\{111\}$  and  $n\{211\}$  varies greatly, even on the same crystal. The faces of  $o$  on some crystals are relatively large, whereas those of  $n$  are very narrow; on other crystals the faces of both forms are about equally developed; and on still other crystals the faces of  $n$  are relatively large, whereas those of  $o$  are mere points. There is a marked tendency for narrow faces of  $o$  to occur along the intersection edges of the faces of  $n$  as oscillatory combinations.

The mineral is isotropic in reflected polarized light (on polished faces parallel to the cube) and shows no indication of twinning. Treatment with dilute HCl did not produce any structures on the polished surfaces.

*Physical properties.*—No cleavage could be detected when several crystals were broken, although Cortelezzi, Himmel, and Schroeder have reported cubic cleavage in the bixbyite from Patagonia. The imperfect octahedral cleavage noted by Penfield is developed on polished surfaces. The fracture is uneven to conchoidal; the color is brilliant black, with metallic luster; the streak is black; hardness is 6 to 6.5; and the specific gravity as determined on the Berman microbalance is 5.05. Penfield and Foote<sup>10</sup> clearly state that 4.945, the specific gravity generally given for bixbyite, is "the specific gravity of the material used for the quantitative analysis. . . ." If this be corrected for  $4\frac{1}{2}$  per cent of included topaz,<sup>11</sup> the specific gravity of the bixbyite from Utah becomes 5.01. The correct specific gravity of bixbyite probably lies in the range of 5.0 to 5.1.

Fragments of bixbyite fuse with difficulty to a black magnetic slag before the blowpipe flame. Under the microscope the finely-crushed fragments transmit a dark smoky-brown color and are completely isotropic. The mineral is too nearly opaque to permit a satisfactory determination of the index of refraction.

*Chemical composition.*—Most of the reported chemical analyses of bixbyite, including an analysis of the new material from New Mexico, are given in Table 5.

The analyses given in Table 5 are restated in Table 6 to express all the oxides in the form of  $R_2O_3$ . In this way a direct comparison of the variability of the ratio of manganese to iron can be better shown.

The molecular ratios and molecular percentages calculated from these figures are shown in Table 7, rearranged in the order of decreasing amounts of  $Mn_2O_3$ .

<sup>10</sup> Penfield, S. L., and Foote, H. W.: *op. cit.*, p. 105.

<sup>11</sup> The percentage calculated on the basis of the alumina in the analysis. See Penfield and Foote, p. 106.

TABLE 5. COMPILATION OF CHEMICAL ANALYSES OF BIXBYITE

	1	2	3					4
			a	b	c	d	e	
SiO <sub>2</sub> <sup>a</sup>	1.21	2.42	1.04	1.18	4.77	2.78	—	—
Al <sub>2</sub> O <sub>3</sub> <sup>a</sup>	2.53	—	—	3.89	3.27	4.24	—	0.47
FeO	—	44.85	52.41	50.99	47.61	48.68	53.21	—
Fe <sub>2</sub> O <sub>3</sub>	47.98	—	—	—	—	—	—	42.54
TiO <sub>2</sub>	1.70	2.05	3.48	2.04	2.35	2.56	3.48	—
Ti <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	—	—	1.57
MnO	42.05	—	—	—	—	—	—	—
MnO <sub>2</sub>	—	50.71	42.37	41.51	42.44	42.03	42.79	—
Mn <sub>2</sub> O <sub>3</sub>	—	—	—	—	—	—	—	51.92
Avail. O	4.38	—	—	—	—	—	—	—
MgO	0.10	0.51	—	0.35	—	—	—	trace
CaO	—	—	—	—	—	—	—	none
Insoluble	—	—	—	—	—	—	—	2.21
	99.95	100.54	99.30	99.96	100.44	100.29	99.48	98.71

<sup>a</sup> Silica and alumina are regarded as impurities.

1. Thomas Range, Utah; H. W. Foote, analyst.
2. Valle de las Plumas, Patagonia; W. Schiller, analyst.
3. Valle de las Plumas, Patagonia; H. Corti, analyst (analyses were made of 5 different groups of crystals).
4. Black Range, New Mexico; W. T. Schaller, analyst (analysis was made on a quarter of a gram and is only approximate). A spectrographic analysis made by George Steiger shows small quantities of tin, copper, and zinc.

Although the values in Table 7 indicate that the ratio of Mn<sub>2</sub>O<sub>3</sub> to Fe<sub>2</sub>O<sub>3</sub> approaches 1:1, only the original analysis of bixbyite from Utah approaches it closely; manganese dominates in the bixbyite from New

TABLE 6. ANALYSES OF BIXBYITE, WITH OXIDES EXPRESSED AS R<sub>2</sub>O<sub>3</sub>

	1	2	3					4
			a	b	c	d	e	
Mn <sub>2</sub> O <sub>3</sub>	46.79	46.04	38.47	37.69	38.53	38.16	38.85	51.92
Fe <sub>2</sub> O <sub>3</sub>	47.98	49.84	58.25	56.67	52.91	54.10	59.13	42.54
Ti <sub>2</sub> O <sub>3</sub>	1.53	1.85	3.13	1.84	2.12	2.30	3.13	1.57
Others	3.84	2.93	1.04	5.42	8.04	7.02	—	2.68
	100.14	100.66	100.89	101.62	101.60	101.58	101.11	98.71

Mexico, whereas iron dominates in the bixbyite from Patagonia. The validity of the formula of bixbyite as  $(\text{Mn}''', \text{Fe}''')_2\text{O}_3$ , as given by Zachariasen<sup>12</sup> and later verified by Pauling and Shappell,<sup>13</sup> is therefore

TABLE 7. MOLECULAR RATIOS AND MOLECULAR PERCENTAGES, REARRANGED IN THE ORDER OF DECREASING AMOUNTS OF  $\text{Mn}_2\text{O}_3$

	Molecular ratios							
	N. Mex.	Utah	Patagonia					
	4	1	2	3c	3d	3a	3e	3b
$\text{Mn}_2\text{O}_3$	.329	.296	.292	.244	.242	.244	.246	.239
$\text{Fe}_2\text{O}_3$	.266	.301	.312	.331	.339	.365	.370	.355
$\text{Ti}_2\text{O}_3$	.011	.011	.013	.015	.016	.022	.022	.013
	Molecular percentages							
	N. Mex.	Utah	Patagonia					
	4	1	2	3c	3d	3a	3e	3b
$\text{Mn}_2\text{O}_3$	54	49	47	41	40	39	39	39
$\text{Fe}_2\text{O}_3$	44	49	51	56	57	58	58	59
$\text{Ti}_2\text{O}_3$	2	2	2	3	3	3	3	2
	—	—	—	—	—	—	—	—
	100	100	100	100	100	100	100	100

substantiated. The analyses suggest that  $\text{Ti}'''$  may also substitute in small quantity for  $\text{Fe}'''$  and  $\text{Mn}'''$ .

In other words, bixbyite is a solid solution of  $\text{Mn}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$ , with a close approach in the analyses from 3 localities to a 1:1 ratio. In this connection it may be noted that the length of the unit cell of artificial  $\text{Mn}_2\text{O}_3$  (9.43, 9.41) is very close to that of bixbyite (9.36)<sup>14</sup>, whereas that of cubic  $\text{Fe}_2\text{O}_3$  ( $\gamma\text{-Fe}_2\text{O}_3$ ) is much smaller (8.30, 8.40).

#### PSEUDOBROOKITE, $\text{Fe}_2\text{O}_3 \cdot \text{TiO}_2$

*Occurrence and association.*—Pseudobrookite was first discovered at

<sup>12</sup> Zachariasen, William, Ueber die Kristallstruktur von Bixbyit, sowie vom künstlichen  $\text{Mn}_2\text{O}_3$ : *Zeits. Krist.*, **67**, 455–471 (1928).

<sup>13</sup> Pauling, Linus, and Shappell, M. D., The crystal structure of bixbyite and the C-modification of the sesquioxides: *Zeits. Krist.*, **75**, 128–142 (1930).

<sup>14</sup> Powder pictures of  $\text{Mn}_2\text{O}_3$  and of bixbyite taken by Dr. W. E. Richmond are identical.

Aranyer Berg, Transylvania, and described by Koch<sup>15</sup> in 1878. Subsequent discoveries have been made at Jumilla, Spain; Mont Dore, France; Havredal, Norway; Katzenbuckel, Baden; Mt. Vesuvius, Italy; Castello Branco, Azores; Berge Hadis, Caucasus; Puy de Dome, France; Crater Lake, Oregon; Hessenbrücker Hammers, Hesse; and in the Thomas Range, Utah. Crystals of artificial pseudobrookite formed by sublimation in a furnace were described by Doss<sup>16</sup> in 1892. A somewhat more complete summary of the history of the mineral is given by Palache.<sup>17</sup>

The discovery of pseudobrookite in the tin-bearing rhyolite in the Black Range in New Mexico is the third recorded occurrence in the United States. The mineral is also widely distributed in vesicles in the rhyolite in the tin-bearing area in northern Lander county, Nevada, examined by one of the authors (C. F.)<sup>18</sup> in the late summer of 1940. It was also found in some of the tin-bearing rhyolites in the states of Guanajuato, Zacatecas, and Durango, Republic of Mexico, by Dr. W. F. Foshag of the National Museum and one of the authors (C. F.) in the early spring of 1941. The mineral is probably widespread in its occurrence but overlooked because of its minute size or its resemblance to some types of amphibole.

Hand specimens of pseudobrookite from the Black Range were collected only from one of the bixbyite localities, as the crystals in the lithophysae there are fairly large and well formed. Fragments of the mineral are present in many of the heavy concentrates made from crushed specimens of the tin-bearing rhyolite. As all the fragments have good crystal faces on unbroken edges and termination on one end, it is assumed that all the pseudobrookite is present in cavities in the rhyolite. Minerals observed in the same cavities with the pseudobrookite are specularite, quartz, and opal. Pseudobrookite is more widely distributed in the tin-bearing rhyolite of the Black Range than is bixbyite.

A resume of the occurrences of pseudobrookite is given in Table 8. The associated minerals are not completely listed, except for the New Mexico and Nevada occurrences.

*Crystallography.*—The shining black prismatic crystals of pseudobrookite from New Mexico reach a length of about a millimeter and

<sup>15</sup> Koch, A., Neue minerale aus dem Andesit des Aranyer Berges in Siebenbürgen: *Tschermak's mineral. u. petrogr. Mittheil.*, new ser., **1**, 331–361 (1878).

<sup>16</sup> Doss, Bruno, Ueber eine zufällige Bildung von Pseudobrookit, Hämatit und Anhydrit als Sublimationsprodukte, und über die systematische Stellung des ersteren: *Zeits. Kryst.*, **20**, 569–584 (1892).

<sup>17</sup> Palache, Charles, Pseudobrookite: *Am. Mineral.*, **19**, 16–20 (1934). Also, Additional notes on pseudobrookite: *Am. Mineral.*, **20**, 660–663 (1935).

<sup>18</sup> Fries, Carl, Jr., Tin deposits of northern Lander county, Nevada: *U. S. Geol. Survey, Bull.* **931**, in press.



TABLE 8. OCCURRENCES OF PSEUDOBROOKITE AND ASSOCIATED MINERALS

Locality	Enclosing rock	Where present	Associated minerals
1. Aranyer Berg, Transylvania	Augite-andesite	In cavities and on fissure walls	Specularite Hypersthene (szaboite) Tridymite Garnet Amphibole Sphene Biotite
2. Jumilla, Spain	Volcanic rocks	?	Specularite Apatite (spargelstein)
3. Mont Dore, France	Augite-andesite	In cavities	Specularite Hypersthene (szaboite) Tridymite
4. Havredal, Norway	?	In veins	Quartz Apatite Feldspar Wagnerite (kjerulfine) Ilmenite?
5. Katzenbuckel, Baden	Nephelinite	In highly altered zone	Apatite Ilmenite
6. Mt. Vesuvius, Italy	Trachyte	In cavities	Mica Hematite Wagnerite? (crifolite) Sellaite (belonesite) Gypsum Anhydrite
7. Castello Branco, Azores	Trachyte	In cavities	Hypersthene (szaboite)
8. Royat, Puy de Dome, France	Basalt	In cavities and on fissure walls	Specularite Pyroxene Feldspar (sanidine?) Magnetite Apatite Biotite
9. Berge Hadis, Caucasus	Augite-andesite	On fissure walls	Hypersthene (szaboite) Specularite
10. Crater Lake, Oregon	Basalt	In cavities	Hypersthene Apatite Tridymite?

TABLE 8. (Continued)

Locality	Enclosing rock	Where present	Associated minerals
11. Hessenbrücker Hammers, Hesse	Basalt	In highly altered zone	Magnetite
12. Thomas Range, Utah	Rhyolite	In cavities	Specularite Bixbyite Topaz Beryl Quartz Garnet Fluorite Calcite
13. Black Range, New Mexico	Rhyolite	In cavities and on fissure walls	Magnetite Bixbyite Specularite Sphene Topaz Garnet Cassiterite Sanidine Quartz Cristobalite Tridymite Chalcedony Opal Zeolites Fluorite Calcite
14. Lander county, Nevada	Rhyolite	In cavities and on fissure walls	Specularite Topaz Garnet Cassiterite Quartz Cristobalite Tridymite Chalcedony Opal Fluorite
15. Guanajuato, Zaca- tecas, and Durango, in Republic of Mex- ico	Rhyolitic lavas	In cavities and on fissure walls	Specularite Topaz Cassiterite Quartz Tridymite Chalcedony Opal Fluorite Zeolites

1. Koch, A.: *Op. cit.*  
Traube, H., Ueber den Pseudobrookit vom Aranyer Berge in Siebenbürgen: *Zeits. Kryst.*, **20**, 331 (1892).
2. Lewis, W. J., Krystallographische Notizen, (1) Pseudobrookit: *Zeits. Kryst.*, **7**, 181-182 (1883).
3. Von Lasaulx, A., Mineralogische Notizen, (2) Szaboit von Riveau grand im Mont Dore: *Zeits. Kryst.*, **3**, 293-294 (1879).  
——, Pseudobrookit und Tridymit von Riveau grand im Mont Dore: *Sitzb. ber. d. schles. Ges. f. vaterl. Cult.*, p. 19, Nov. 1879. (Abstr. in *Zeits. Kryst.*, **6**, 203, 1882.)
4. Cederström, Anders, Pseudobrookit in grossen Krystallen von Havredal, Bamle, Norwegen: *Zeits. Kryst.*, **17**, 133-136 (1890).
5. Lattermann, Georg, Untersuchungen über den Pseudobrookit: *Tschermak's mineral. u. petrogr. Mittheil.*, new ser., **9**, 47-54 (1887).
6. Krenner, J. A., Ueber den Pseudobrookit vom Vesuv: *Földtani Közlöny*, **18**, 153-157 (1888). (Abstr. in *Zeits. Kryst.*, **17**, 517-518, 1890.)
7. Mügge, O., Petrographische Untersuchungen an Gesteinen von den Azoren: *Neues Jahrb. f. Min., Geol., u. s. w.*, **2**, 194-196 (1883).
8. Lacroix, A. and Gautier, P., Sur les minéraux des fumerolles basaltiques de Royat (Puy de Dome): *Compt. Rend.*, **126**, 1529-1532 (1898).
9. Dannenberg, A., Beiträge zur Petrographie der Kaukasusländer, (2) Schluss: *Tschermak's mineral. u. petrogr. Mittheil.*, new ser., **23**, 26-29 (1904).
10. Diller, J. S. and Patton, H. B., The geology and petrology of Crater Lake National Park: *U. S. Geol. Survey, P.P.* **3**, 146-148 (1907).
11. Von Ramdohr, Paul, Ein neues Vorkommen von Pseudobrookit: *Notizblatt des Vereins f. Erdkunde u. der Hess. Geol. Landesanstalt zu Darmstadt*, ser. 5, pt. 5, 191-193, 1920 (published 1923).
12. Palache, Charles, Minerals from Topaz Mt., Utah: *Op. cit.*  
Montgomery, Arthur: *Op. cit.*
13. Present paper.
14. Fries, Carl, Jr., Tin deposits of northern Lander county, Nevada: *Op. cit.*
15. Found by Dr. W. F. Foshag of the National Museum and one of the authors (C.F.) during a reconnaissance of the tin deposits of Mexico. (List of associated minerals is not complete.)

are about half to a fifth as wide. They are slightly flattened parallel to the front pinacoid, and in the prism zone the faces are strongly striated. In general habit they resemble the crystal from Topaz Mountain, Utah, shown by Palache.<sup>19</sup>

Three crystals were measured. Two of these (nos. 2 and 3) were attached to each other at a small angle, with a third, smaller and more needle-like crystal, not measured, projecting out from the two larger crystals. In most of these occurrences of pseudobrookite there is a marked tendency for several crystals to form slightly radiating groups. The forms present are given in Table 9.

The averages of the measured angles are given in Table 10.

The 6 new forms were all narrow prism faces. The measurements are given in Table 11.

<sup>19</sup> Palache, Charles, Pseudobrookite: *Op. cit.*, p. 19.

TABLE 9. FORMS ON THREE PSEUDOBROOKITE CRYSTALS FROM NEW MEXICO

Known forms	$a\{100\}$ $l\{301\}$	$b\{010\}$ $s\{121\}$	$h\{340\}$ $p\{131\}$	$m\{110\}$	$\mu\{210\}$	$e\{101\}$
New forms	$d\{560\}$	$g\{650\}$	$f\{11.10.0\}$	$i\{320\}$	$j\{830\}$	$k\{410\}$

The faces of  $f\{11.10.0\}$ ,  $i\{320\}$ , and  $j\{830\}$  are all line faces, whereas some faces of  $k\{410\}$ ,  $g\{650\}$ , and  $d\{560\}$  are as broad as some faces of  $\mu\{210\}$ .

TABLE 10. AVERAGE MEASURED AND CALCULATED ANGLES OF PSEUDOBROOKITE FROM NEW MEXICO

$a:b:c=0.9777:1:0.3727$  (Palache 1934)

Forms	No. crystals	No. faces	Measured		Calculated	
			$\phi$	$\rho$	$\phi$	$\rho$
$b\{010\}$	1	1	0°00'	90°00'	0°00'	90°00'
$a\{100\}$	3	4	90 16	89 54	90 00	90 00
$h\{340\}$	1	1	36 44	90 00	37 30	90 00
* $d\{560\}$	2	6	40 20	89 47	40 27	90 00
$m\{110\}$	1	1	46 51	90 25	45 39	90 00
* $f\{11.10.0\}$	3	4	48 19	90 16	48 22	90 00
* $g\{650\}$	2	3	50 40	89 57	50 50	90 00
* $i\{320\}$	3	3	56 52	90 06	56 54	90 00
$\mu\{210\}$	3	6	63 58	89 55	63 57	90 00
* $j\{830\}$	3	6	69 23	89 43	69 52	90 00
* $k\{410\}$	3	6	76 44	89 44	76 15	90 00
$e\{101\}$	1	2	89 57	21 18	90 00	20 52
$l\{301\}$	3	5	89 33	48 58	90 00	48 50
$s\{121\}$	3	7	27 45	40 26	27 05	39 56
$p\{131\}$	3	10	18 51	49 31	18 50	49 45

\* New forms.

The dominant terminal form is  $l\{301\}$ , with the faces of  $p\{131\}$  much smaller. The unit front dome  $e\{101\}$  was observed on only one crystal as extremely narrow line faces. The faces of  $s\{121\}$  are mostly very small; some faces reflected mere points of light without signal. No faces of the unit pyramid  $q\{111\}$  were observed on any of the crystals.

Only one face of  $b\{010\}$  is present. Some faces of  $a\{100\}$  are replaced by a set of alternating striations or occur with other prisms as a continuous set of strongly striated narrow faces. On the rear side of crystal



TABLE 11. MEASUREMENTS OF SIX NEW PRISM FORMS ON PSEUDOBROOKITE FROM NEW MEXICO

Form	Crystal no.	Measured		Form	Crystal no.	Measured	
		$\phi$	$\rho$			$\phi$	$\rho$
$d\{560\}$	1	40°48'	89°20'	$i\{320\}$	1	57°03'	90°05'
	1	39 16	88 33		2	55 47	90 25
	1	40 51	90 00		2	57 06	89 52
	2	40 19	90 00		3	57 30	90 00
	2	39 51	90 25			(Calculated)	
	2	40 55	90 25		56 54	90 00	
		(Calculated)		$j\{830\}$	1	70 34	88 33
		40 27	90 00		2	69 59	90 36
					2	69 20	89 14
					2	68 39	89 52
			3		68 32	90 00	
$f\{11.10.0\}$	1	47 29	90 14	3	69 15	90 00	
	2	48 57	90 25		(Calculated)		
	2	48 51	90 25		69 52	90 00	
	3	47 57	90 00				
		(Calculated)					
		48 22	90 00				
$g\{650\}$	1	51 36	89 20	$k\{410\}$	1	75 30	89 59
	1	50 06	90 05		1	77 14	89 59
	2	50 18	90 25		2	77 09	90 00
					2	76 28	89 14
					2	76 47	89 13
		(Calculated)			3	77 16	90 00
		50 50	90 00			(Calculated)	
						76 15	90 00

no. 1, the broad face is  $(\bar{2}10)$  with line faces of  $(\bar{1}\bar{1}.10.0)$ ,  $(\bar{6}50)$ ,  $(\bar{3}20)$ ,  $(\bar{4}10)$ , and  $(\bar{5}\bar{6}0)$  and narrow faces, much broader than line faces, of  $(\bar{1}00)$ ,  $(\bar{4}\bar{1}0)$ ,  $(\bar{2}10)$ , and  $(\bar{6}\bar{5}0)$ , the striated zone extending from  $(\bar{1}\bar{1}.10.0)$  through  $(\bar{2}10)$  to  $(\bar{5}\bar{6}0)$ . The faces of  $m\{110\}$  are likewise replaced by sets of striations containing the forms  $d\{560\}$ ,  $f\{11.10.0\}$ ,  $g\{650\}$ , and  $i\{320\}$ . Only one face gave a reading close to the  $\phi$  value of  $m\{110\}$ .

#### ORIGIN

Bixbyite has been found in rhyolite and in trachyte; pseudobrookite occurs in rocks that vary in composition from rhyolite to basalt. In all the occurrences, except two of those for pseudobrookite (nos. 4 and 5 in Table 8), the enclosing rock is a lava flow or an associated pyroclastic

bed. In each occurrence the bixbyite and the pseudobrookite formed later than the enclosing rock, either in cavities, on fissure walls, or in veins; neither mineral has been found as a pyrogenetic accessory.

It is clear that pseudobrookite may form by sublimation, for it has been found in the flues of furnaces in a soda factory.<sup>20</sup> At Mt. Vesuvius it was found in cavities in lavas less than 16 years after they were extruded. Earlier writers have attributed its origin to vapors escaping from bodies of cooling lava, in some places as fumaroles. The similarity in the occurrences for bixbyite and pseudobrookite suggests that they are formed by similar processes. It is reasonable to attribute the origin of the bixbyite and the pseudobrookite in the tin-bearing rhyolite of the Black Range to vapors escaping from the cooling flows.

<sup>20</sup> Doss, Bruno: *Op. cit.*

## NOTES AND NEWS

### NOTES ON SOME MINERALS FROM SOUTHERN CALIFORNIA. III\*

JOSEPH MURDOCH AND ROBERT W. WEBB,  
*University of California, Los Angeles.*

In this paper have been grouped a number of brief descriptions of new mineral localities in southern California, and observations on some localities previously described. It is the intention of the writers to publish similar assembled data from time to time, in the hope that in this way the information may be made more readily available than if issued as separate items.

#### LINARITE AND ASSOCIATED MINERALS FROM DARWIN, INYO COUNTY, CALIFORNIA

This note describes linarite, aurichalcite, and a number of associated minerals collected from the Defiance Mine. No new minerals for California were found, but several in the list are new for the locality. The minerals may be grouped into two classes: the original country rock and ore minerals, and their alteration products. The geology and ore deposits of the Darwin district have been described by Knopf<sup>1</sup> and Kelley,<sup>2</sup> but the authors did not give or describe a complete list of the minerals occurring there.

#### PRIMARY MINERALS

*Calcite.* Coarsely crystalline limestone; the country rock.

*Fluorite.* Massive, cleavable material, often pale purple in color, occurring as patches and stringers in the calcite.

*Galena.* Massive, cleavable, occurring in the limestone in much the same manner as fluorite.

*Pyrite.* Cubic crystals scattered through the calcite matrix.

#### SECONDARY MINERALS

These are the products of surface, or near surface, alteration of the ores, and occur in general as coatings, or cavity fillings in the leached primary ore.

*Anglesite.* It occurs as fine grained, massive white incrustations on galena, or less com-

\* Notes on some minerals from southern California: I., *Am. Mineral.*, **23**, 349-355 (1938); II., *Am. Mineral.*, **25**, 549-555 (1940).

<sup>1</sup> Knopf, Adolph., The Darwin silver-lead mining district, California: *U. S. Geol. Surv., Bull.* **580**, 1-18 (1915).

<sup>2</sup> Kelley, Vincent C., Geology and ore deposits of the Darwin silver-lead mining district Inyo County, California: *Calif. Bur. Mines, Bull.* **34**, 503-562 (1938).

monly as aggregates of minute tabular, colorless crystals, with narrow pyramid faces  $\{111\}$ , modifying the dominant base and unit prism.

*Aurichalcite*. This mineral has not been reported heretofore from this locality. Its identification was confirmed by microchemical tests for copper and zinc. The aurichalcite occurs rather abundantly as rosettes and hemispheres of radiating needles, blue-green in color, and usually coated completely with transparent hemimorphite. Sometimes the needles are entirely uncovered, and project from the surface in delicate tufts.

*Calcite*. A second generation of this mineral appears as minute flat rhombohedra on the surface of the hemimorphite, often associated closely with later fluorite.

*Fluorite*. In addition to the massive purple fluorite of the primary ore, fluorite occurs in tiny colorless octahedra on the surface of hemimorphite, or on other secondary minerals. It is usually the latest of this series of minerals.

*Hemimorphite*. Colorless or white hemimorphite occurs as an abundant and often thick crust of imperfect crystals on fracture surfaces or cavity walls. Occasionally a single individual may be isolated; one such crystal showed on measurement the following forms:  $\{010\}$ ,  $\{110\}$ ,  $\{011\}$ ,  $\{101\}$ , and  $\{301\}$ . Some of the hemimorphite appears green, due to an undercoating of aurichalcite, the color of which is transmitted through the overlying colorless crust.

*Hydrozincite*. This mineral occurs as a crust of white or colorless blade-like crystals, showing no terminal faces; or as a white, fine grained coating. It is usually late in the paragenetic sequence.

*Limonite*. It occurs as pseudomorphs after pyrite, or as powdery coatings and crusts.

*Linarite*. Linarite has not previously been reported from Darwin. It occurs as crusts and coatings of brilliant blue crystals and grains, late in the sequence since it is seldom

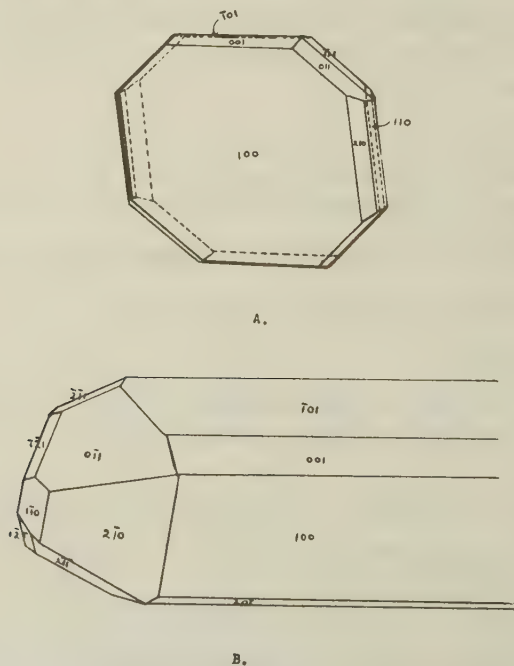


FIG. 1



covered by other secondary minerals. Its identification was made by tests for copper, lead and  $\text{SO}_4$ , and crystallographic measurements. The crystals are mostly quite small, and appear in two habits: first, short prismatic, parallel to the  $b$ -axis; second, thin tabular, parallel to  $\{100\}$ . Typical crystals with these habits are shown in Fig. 1, A and B. The prismatic crystals have no important dominant form, but usually  $\{\bar{1}01\}$  is better developed than the others in the orthodome zone. Less common are:  $\{201\}$   $\{701\}$   $\{302\}$ . One crystal shows a narrow face close to  $\{39 \cdot 0 \cdot 20\}$ . Measured and calculated readings for this face follow:

	Measured	Calculated
$\phi_2$	$126^\circ 49'$	$126^\circ 34\frac{1}{2}'$
$\rho_2$	$-90 \ 00$	$-90 \ 00$

The terminations frequently show good prism faces,  $\{110\}$  and  $\{210\}$ , and often  $\{011\}$  or  $\{211\}$ . Less common are:  $\{\bar{1}21\}$ ,  $\{\bar{1}11\}$ . The tabular crystals are frequently twinned on  $\{100\}$ , as shown by the repetition of  $\{\bar{1}01\}$ ,  $\{001\}$  or  $\{\bar{1}\bar{1}1\}$ . The dominant form is  $\{100\}$ , modified by narrow faces, some of them mere lines, of  $\{001\}$ ,  $\{101\}$ ,  $\{110\}$ ,  $\{120\}$ ,  $\{\bar{1}11\}$ . Less commonly  $\{211\}$  takes the place of  $\{\bar{1}11\}$ .

*Malachite*. This mineral never occurs in good crystals, but is rather common as a coating of minute flakes and fibers on cavity surfaces.

*Wulfenite*. In some of the cavities a few shapeless grains of wulfenite were seen.

#### ORTHOCLASE PHENOCRYSTS FROM CINCO, CALIFORNIA

An interesting occurrence of orthoclase crystals has been the collecting ground of hundreds of collectors for the past few years near Cinco, a wayside railroad station on the Owenyo branch of the Southern Pacific Railroad, about fifteen miles north of Mojave, California. This locality was known as early as 1908, when Cinco, then a boom town of 1000 population or more, was a center of activity during the construction of the Los Angeles/Owens River aqueduct, which was completed in 1913. It was not until about 1928 that the locality became generally known. In spite of the present widespread distribution of the orthoclase (mostly twinned) crystals from this locality, no geological or mineralogical description of them has ever appeared. The locality is represented in almost all California collections of minerals, and has widespread representation in collections all over North America. Not only are the specimens noted for their abundance, but also for size, perfection of development, and variety of forms. The locality is now more famous than the well-known locality at Goodsprings, Nevada, crystals from which were recently studied.<sup>3</sup> The collecting grounds are reached by an aqueduct inspection road turning from State Highway No. 7 from Mojave to Little Lake, California, one-quarter mile north of a wayside gasoline station called Cinco. The road ascends the Sierran escarpment by a series of switchbacks. The right hand fork is followed wherever a junction is encountered. After about four miles, an elongate ridge summit is reached, where the road retraces

<sup>3</sup> Drugman, J., On some unusual twin-laws observed in the orthoclase crystals of Goodsprings, Nevada: *Mineral. Mag.*, **25**, 1-14 (1938).

on the opposite side of the ridge. The car may be parked at this point as the locality is east along the ridge.

The geology of the general region is discussed by Baker.<sup>4</sup> No one has, however, noted the specific geologic conditions in the region. Areally the most extensive formation is the quartz monzonite-granodiorite of the Sierra Nevada batholith, which includes in this area few remnants of the older metamorphic sequence, represented by fragmentary xenoliths of quartzites; these are more or less continuous with, and lithologically like, the Kernville Series<sup>5</sup> to the north. This sequence is intruded by a number of rhyolite dikes varying in thickness from eight or ten feet up to 30 or 40, with generally a steep dip (40°–50° NE) and westerly strike (N 40° W). Many of these dikes, and in particular the southernmost of the group, are characterized by many well developed phenocrysts of orthoclase, ranging in size from 1 up to 10 cm. in length. There are also abundant phenocrysts of quartz, seldom over 1 cm. across, and usually much less. Commonly the dikes show a fine grained chilled margin phase, without phenocrysts.

The phenocrysts, both of feldspar and quartz, may be readily broken out of the matrix where the rock is weathered, and supply excellent specimens of well formed crystals. The feldspars are practically all Carlsbad twins, with an occasional Baveno twin, and much less commonly single individuals. The quartz crystals are invariably simple bipyramids, with the prism either absent or very slightly developed, with rounded edges or surfaces. Both minerals occur in a relatively fine-grained groundmass made up of orthoclase, quartz, biotite, and plagioclase. In thin section, the biotite is rare, and much of the plagioclase occurs as small, idiomorphic crystals and as a fine-grained aggregate of interlocking grains. This feldspar shows a maximum extinction angle of  $15^\circ \pm$  and is probably near andesine (An<sub>35–40</sub>) in composition. The quartz shows considerable resorption. The orthoclase is only slightly affected by resorption, and is ordinarily only slightly altered. The alteration products are kaolinite and sericite. The plagioclase is all badly altered, with the prominent development of calcite. The biotite has been occasionally preserved where included in an orthoclase grain, but elsewhere is completely altered to mixtures of chlorite and sericite.

<sup>4</sup> Baker, C. L., Physiography and structure of the western El Paso Range and southern Sierra Nevada: *Univ. Calif. Pub. Bull., Dept. Geol.*, **7**, 117–142 (1912).

<sup>5</sup> Miller, William J., Geologic sections across the southern Sierra Nevada of California: *Univ. Calif. Pub. Bull., Dept. Geol. Sci.*, **20**, 331–360 (1931);—and Webb, Robert W., Descriptive geology of the Kernville Quadrangle, California: *Calif. Jour. Mines and Geol., Rept.* **36**, 343–378 (1940).

One orthoclase crystal, almost completely kaolinized, was seen in thin section to be filled with inclusions of plagioclase, some rectangular, others showing definite crystal outlines, and arranged in parallel orientation. This orientation differs in the different halves of the Carlsbad twin of orthoclase, and all or most of the inclusions are albite twins.

Many of the orthoclase phenocrysts, even the freshest in appearance, on being broken, showed cores or small patches of a soft, pale bluish material, probably chlorite (or possibly talc, since it is very fine grained) which has apparently been derived from the alteration of original biotite or some other mafic mineral.

The orthoclase phenocrysts show dominant development of the pinacoids {010}, {001}, the prism {110}, negative dome  $\{201\}$ , and less commonly small modifying forms of  $\{\bar{1}11\}$  and {120}. Except where badly kaolinized, the crystal surfaces are smooth and the edges and corners sharp. Since there are no roadcuts or workings exposing these dikes, no entirely fresh material was available.

#### HEMIMORPHITE CRYSTALS FROM LEAD HILL MINE, BARSTOW, CALIFORNIA

About five miles northeast of Barstow, at the locality known as Lead Hill, occurs a series of fissure veins in metamorphic rocks carrying a variety of minerals. Some of these veins were mined for lead and silver in the early days. Most of the gangue material is barite, which, where the deposit is vuggy, shows well developed and often fairly large crystals. These are simple tabular crystals with base and prism. In addition, there occurs considerable coarsely cleavable calcite stained brown by oxide and closely resembling siderite. Less common, and often associated with residuals of galena, occur crusts of minute perfect hemimorphite crystals, rarely over 1 mm. in length, and often needle-like in appearance. These have been presumably derived from the alteration of sphalerite, though none of this mineral has been identified.

At one point in this locality, where the veins apparently cut limestone, and other calcareous rocks, thin coatings of malachite, and rarely of azurite, were noticed. Here also, are occasional thin crusts and minute globular masses of a yellowish-green mineral giving microchemical tests for Cu, Pb, Ca, As, and Cl; this may be a cupriferous hedyphane, although the material so far found is too scanty to make this identification definite. Aurichalcite allegedly occurs at this locality but it has not been found, all supposed specimens so far tested proving to be malachite. From some of the workings, small grains of wulfenite, not showing crystal form, have been collected.

# CORUNDUM AND ASSOCIATED MINERALS NEAR BANNING, SAN JACINTO MOUNTAINS, CALIFORNIA

In 1939, large crystals of corundum embedded in mica schist were submitted to the Department of Geology of the University of California, Los Angeles, by Mr. B. G. Funk, of Los Angeles. The specimens were of special interest because the corundum showed sapphire-blue cores, and was progressively zoned outward, sapphire-blue alternating with dull gray, and micaceous material. The locality was visited with the permission of the owner in the hope of finding sapphire of commercial quality. While this hope was not realized it is thought that the locality warrants further description, a brief account of its discovery having recently been published by Mr. Guy E. Hazen,<sup>6</sup> of Wickiup, Arizona, to whom the writers are indebted for permission to collect at the locality.

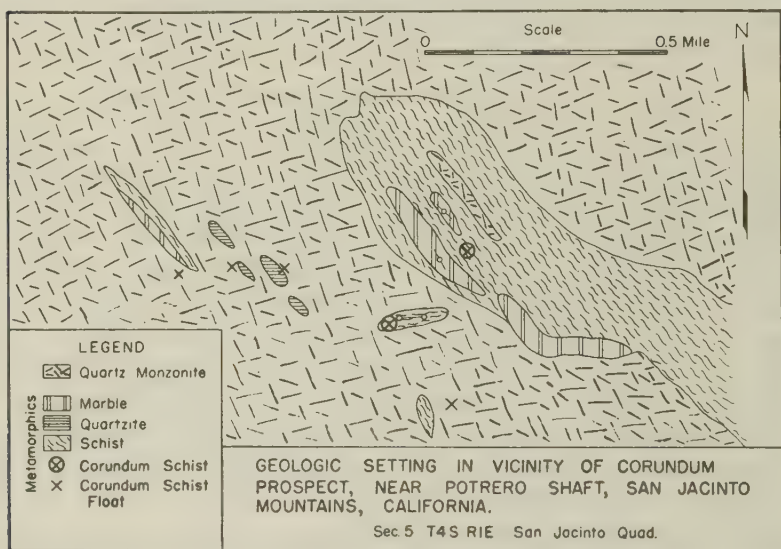


FIG. 2

The locality, situated on the northwestern flank of San Jacinto Mountains, in Sec. 5, T4S, R1E, San Jacinto Quadrangle, is readily accessible from the Potrero shaft of the Metropolitan Water District's Aqueduct system, being about two miles from the mouth of the shaft. The geology of the region has been described in reconnaissance by Fraser,<sup>7</sup> and in de-

<sup>6</sup> Hazen, Guy E., Corundum crystals—California: *The Mineralogist*, 9, 81-82 (1941).

<sup>7</sup> Fraser, Donald M., Geology of San Jacinto Quadrangle south of San Geronio Pass: *Calif. Bur. of Mines, State Mineralogist Report*, 27, 494-540 (1937).



tail from observations along the line of a tunnel of the Los Angeles Metropolitan Water District, by Henderson.<sup>8</sup> A detail of the geology of the corundum deposit is given in Fig. 2.

The rocks consist of a series of metasedimentary types, mica schists, quartzites, and marbles, present chiefly in large roof pendants and smaller xenolithic masses, remnants of a more extensive sequence of unknown, but presumed, Paleozoic age. These are extensively intruded in the general region by diorites and gabbros, followed by granite and quartz monzonite, the latter only present in the corundum area. Widespread erosion has resulted in deeply weathered soil slopes especially in the plutonic rocks, with the hills supported by metamorphic remnants.

The corundum occurs in the usual barrel-shaped crystals, varying from microscopic size to individuals 14 inches in length and up to two inches in diameter. The crystals are coated externally with muscovite and biotite rims, making the hardness deceptive. The crystals occur both parallel and transverse to the foliation of the biotite schist, which in places is almost a biotite gneiss. The crystals are occasionally sufficiently blue so that the color is megascopically visible, but in several hundred specimens examined, none was found suitable for cutting. That corundum-bearing rocks have a wide distribution in the general sector is suggested by the many fragments of crystals picked up on weathered slopes within a mile of the main exposure. Similar corundum crystals have been found as float in many other parts of the San Jacinto Mountains.

The corundum in this occurrence is thought to have formed during the metamorphism of a highly aluminous sedimentary rock, under initial dynamothermal conditions. No evidence suggesting the introduction of aluminous material during invasion of batholithic rocks younger than the metasedimentary sequences was found.

Adjacent to the corundum deposit, along the contact of the large roof pendant shown in Fig. 2, are found several areas of garnet-diopside-wollastonite-quartz mineralization, formed on contacts by silicification of the marbles of the pendant. Impregnation by silicate solutions has extended into the pendant through a zone 100 yards wide, with development of massive and crystallized grossularite in a matrix of white quartz, calcite and large radiating clusters of white wollastonite. Diopside is also present in minor amounts. The absence of aluminous minerals in this tactite is considered significant in relation to the corundum since, were the corundum formed at the same time as the tactite zone, by the quartz monzonite intrusive, aluminous minerals would be expected in the tactite as well as in the xenoliths of biotite schist.

<sup>8</sup> Henderson, L. H., Detailed geological mapping and fault studies of the San Jacinto tunnel line and vicinity: *Jour. Geol.*, **47**, 314-325 (1939).

ZEOLITES AND ASSOCIATED MINERALS FROM  
RED ROCK CANYON, CALIFORNIA

Red Rock Canyon, one of the scenic canyons of the Mojave Desert, 120 miles from Los Angeles, is carved across a tilted fault block, known as the El Paso Mountains. Exposed in the canyon are a basement complex of granitic rocks and associated old metasedimentary types intruded by plutonic sequences, all of which are overlain unconformably by a sequence of bedded rocks, composed of water-laid tuffs and ash beds, and intercalated basaltic lavas. This sequence is colored pink, green, and white in varying intensities, which, in contrast to the black basalts makes a spectacular panorama when viewed at the correct time of day. The geologic setting of the canyon has been briefly discussed by several writers.<sup>9</sup>

The minerals of interest are found in the cavities of the basaltic flows, which are sometimes uniformly vesicular and amygdaloidal. The amygdules are usually geodal, with interesting small, but perfect, crystals in each cavity. Commonly several minerals are found, including analcite, natrolite, calcite, the quartz family minerals—quartz, chalcedony, jasper—and occasionally opal. In other parts of the same region, opal is unusually abundant, and has been prospected commercially.

Analcite occurs in perfect, white to transparent, trapezohedrons, often completely encrusting vesicular cavities in the basalt. Analcite crystals vary from microscopic size up to .5 cm. in diameter. Projecting into the amygdules, resting on the analcite, are prisms of natrolite, in radiating bundles of transparent crystals. The crystals are usually .5–1.0 cm. in length, and diverge radially into individual prisms capped by a simple pyramid. Other specimens show crystals of calcite filling the balance of the amygdule; at other times chalcedony completes the filling. More commonly, however, natrolite is the last mineral to form in the cavities. Some vesicles are completely filled with red, yellow, or greenish jasper, or, on occasion, with opal. Quartz geodes are usually preceded by chalcedony linings and followed by natrolite or calcite.

The general paragenetic sequence is clear, but exceptions to each case were noted. Chalcedonic solutions were permeating the basalts throughout the period of formation of the entire sequence, because chalcedony forms the initial linings and final fillings for some vesicles. Analcite followed the chalcedony, as coatings of analcite trapezohedrons on chalcedony are common. Natrolite or calcite came next, the sequence indeterminate. However, natrolite and analcite must have partially overlapped because a few sharp natrolite crystals have analcite crystals perched on the natrolite terminations. This condition is rare, however. Where jasper and opal fill vesicles, no other minerals have been found.

<sup>9</sup> Baker, C. L., *op. cit.* (1912); Miller, William J., Red Rock Canyon, California: *Jour. Geog.*, 25, 330–336 (1926).

## CONSERVATION OF SCHOLARLY JOURNALS

The American Library Association created this last year the Committee on Aid to Libraries in War Areas, headed by John R. Russell, the Librarian of the University of Rochester. The Committee is faced with numerous serious problems and hopes that American scholars and scientists will be of considerable aid in the solution of one of these problems.

One of the most difficult tasks in library reconstruction after the first World War was that of completing foreign institutional sets of American scholarly, scientific, and technical periodicals. The attempt to avoid a duplication of that situation is now the concern of the Committee.

Many sets of journals will be broken by the financial inability of the institutions to renew subscriptions. As far as possible they will be completed from a stock of periodicals being purchased by the Committee. Many more will have been broken through mail difficulties and loss of shipments, while still other sets will have disappeared in the destruction of libraries. The size of the eventual demand is impossible to estimate, but requests received by the Committee already give evidence that it will be enormous.

With an imminent paper shortage attempts are being made to collect old periodicals for pulp. Fearing this possible reduction in the already limited supply of scholarly and scientific journals, the Committee hopes to enlist the cooperation of subscribers to this journal in preventing the sacrifice of this type of material to the pulp demand. It is scarcely necessary to mention the appreciation of foreign institutions and scholars for this activity.

Questions concerning the project or concerning the value of particular periodicals to the project should be directed to Wayne M. Hartwell, Executive Assistant to the Committee on Aid to Libraries in War Areas, Rush Rhees Library, University of Rochester, Rochester, New York.

WAYNE M. HARTWELL

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Harry Ward Foote, professor of chemistry at Yale University, died January 14, 1942. Although his work during the forty-two years he was a member of the Yale faculty was chiefly in physical chemistry, his early training under S. L. Penfield created an interest in mineralogy which he always retained. In the years 1896-1899, he described the new minerals bixbyite, clinohedrite and roeblingite (all these with Penfield) and wellsitite (with J. H. Pratt), and published important papers on the formulae of tourmaline and of ilmenite. In 1911-1914, he published a series of papers with W. F. Bradley on isomorphism in minerals, which included data on nepheline, analcime, albite, chrysocolla, calcite and dolomite. Some of his papers in physical chemistry were also of mineralogical interest, such as his studies of the physico-chemical relationships between calcite and aragonite, of the solubility relations of datapskite and of schairerite. Many members of the Society had the good fortune to attend his lectures on the phase rule, in which he called attention to geological applications.

MICHAEL FLEISCHER



## BOOK REVIEWS

FORTUNES IN MINERALS—SIMPLE TESTS AND HOW TO MAKE THEM. ION L. IDRIESS. 222 pages. Angus and Robertson, Ltd., Sydney, Australia. 1941. Price \$2.50.

This book, like a number of others that have appeared recently, is designed to meet the needs of the practical miner and prospector. It is written especially for those engaged in seeking minerals of economic value in Australia. The presentation is simple and direct as no previous scientific training is assumed. Not a single chemical symbol or equation is given in the entire book.

The author describes the occurrence and uses of the important economic minerals and records tests for their identification that can be applied with meagre and inexpensive equipment. Attention is also called briefly to a few of the more common rock types and the minerals that might accompany them.

The book contains much interesting information and should prove of considerable value to the special group for whom it was written.

W.F.H.

PRACTICAL GEMMOLOGY—A STUDY OF THE IDENTIFICATION OF GEM-STONES, PEARLS, AND ORNAMENTAL MINERALS, by ROBERT WEBSTER. vi+180 pages, with four half-tone plates and fifty-four figures. N. A. G. Press Ltd., London (1941).

This volume is a companion to the author's *Gemologist's Pocket Compendium*, published in 1937. The fundamentals of gemmology are presented in 19 lessons. In order to aid the student, there is a recapitulation and a set of test questions at the end of each lesson. On account of the limitation of space, the treatment is necessarily concise. Eighteen of the more important gem minerals and seventeen of what the author designates as unusual gem stones are described. The volume should prove helpful to those desiring an elementary knowledge of the subject.

EDWARD H. KRAUS

MINERALS OF ARIZONA by F. W. GAILBRAITH. Arizona Bureau of Mines, Geological Series No. 15, Bulletin 149 (1941). Price 50 cents (free to residents of Arizona).

Brief descriptions and occurrences are given for about 275 minerals that have been found in Arizona. The pamphlet of 82 pages represents a compilation made from publications and manuscripts.

W.F.H.

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The Society of Economic Geologists, on the recommendation of a committee consisting of B. S. Butler, T. S. Lovering, and Adolph Knopf, Chairman, has awarded its Penrose Medal to Professor William H. Emmons, of the University of Minnesota, in recognition of his outstanding contributions to the science of Economic Geology. The presentation was made on February 10, 1942, at the annual dinner of the Society in New York.

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Dr. A. E. Alexander, director of the Bureau of Natural Pearl Information, has accepted a position as research ceramic engineer with the B. G. Aviation Mica Spark Plug Corporation, of New York, for the duration of the war.



## NEW MINERAL NAMES

### Sarmientite

VICTORIO ANGELELLI AND SAMUEL G. GORDON: Sarmientite, a new mineral from Argentina, *Notulae Naturae Acad. Nat. Sci. Phila.*, no. 92, 4 pp. (1941).

NAME: For Domingo Faustino Sarmiento (1811–1888), who was Minister of Public Instruction, Minister of the Interior, and President of the Argentine Republic.

CHEMICAL PROPERTIES: A basic arsenate-sulfate of iron, sulfate destinezite. Analysis by Paul Collins gave:  $\text{SO}_3$  18.28,  $\text{As}_2\text{O}_5$  22.68,  $\text{Fe}_2\text{O}_3$  36.57,  $\text{CaO}$  0.27,  $\text{H}_2\text{O}$  2.286; sum 100.66%.

CRYSTALLOGRAPHIC PROPERTIES: Occurs as prismatic crystals 2 to 25 microns in length. Monoclinic,  $2/m$ ;  $a:b:c=0.3415:1:0.5242$ ,  $\beta$   $97^\circ 39'$ . Only three forms were observed,  $b\{010\}$ ,  $m\{110\}$ , and  $w\{011\}$ .

PHYSICAL AND OPTICAL PROPERTIES: Color pale yellow-orange. Gr. 2.58. Optically positive,  $\alpha=1.628$ ,  $\beta=1.635$ ,  $\gamma=1.689$ ,  $X=a$ ,  $Y=b$ ,  $Z/c=12^\circ$ .

OCCURRENCE: Found in the iron sulfate deposits (alcaparossa) of the "Santa Elena" mine, Dept. of Barreal, where a vein of pyrite, sphalerite, chalcopyrite and arsenopyrite in diabase has been oxidized. Associated minerals are fibroferite, copiapite, botryogen, szomolnokite, gypsum, and epsomite.

DISCUSSION: X-ray comparison with the optically amorphous iron sulfate-arsenate mineral pitticite would be of interest.

MICHAEL FLEISCHER

### Calingastite

VICTORIO ANGELELLI AND ROGELIO A. TRELLES: Las alubreras de Rodeo y Barreal y los sulfatos de hierro de La Alcaparossa (Prov. de San Juan). *Boletín de Obras Sanitarias de la Nación*, Buenos Aires, Nos. 8, 9, 10, p. 41 (1938); quoted by Angelelli and Gordon, *Notulae Naturae Acad. Nat. Sci. Phila.*, no. 92 (1941). A zincian melanterite  $(\text{Fe}, \text{Zn}, \text{Cu})\text{SO}_4 \cdot 7\text{H}_2\text{O}$ , containing FeO 16.67, ZnO 8.42, CuO 1.29%. Occurs with sarmientite (see above).

M. F.

### Tantalo-rutile

A. B. EDWARDS: A note on some tantalum-niobium minerals from Western Australia. *Australasian Institute Mining and Metallurgy*, no. 120, p. 731 (1940). A new name suggested in place of ilmenorutile, which is considered to be an unfortunate name. Study of several specimens indicates that ilmenite and tantalo-rutile form a solid solution at high temperature, but become immiscible on cooling.

DISCUSSION: The name ilmenorutile is usually applied to the Cb-rich mineral and the name strueverite to the Ta-rich. The name tantalo-rutile is therefore an unnecessary synonym for strueverite. Edwards applies the name tantalo-rutile to both Cb-rich and Ta-rich material.

M. F.

### Nifesite

H. LÖFQUIST AND C. BENEDICKS: Det stora Nordenskiöldska järnblocket från Ovifak. *K. Svenska Vetenskaps. Handl.*, Band 19, No. 3, 94 pp. (English summary pp. 89–93) (1941).

NAME: From the composition (Ni, Fe, S). The name is applied to a very fine-grained aggregate, seemingly a low temperature decomposition structure, of bravoite and pentlandite. Numerous excellent photomicrographs are given. The intergrowth of bravoite and pentlandite occurs in the terrestrial iron from Ovifak, Greenland, which was brought to Stockholm by Nordenskiöld.

DISCUSSION: This is not a mineral name, but belongs in the same category as pearlite, plessite, etc.

M.F.

# ERRATA

Errata in the paper by Palache and Lewis, Crystallography of azurite from Tsumeb, Southwest Africa, and the axial ratio of azurite: *Am. Mineral.* **12**, 99-143 (1927).

Most of the following corrections apply to the angle tables on pages 106-109, and 110-112. Since the forms are in the same sequence in the two tables and bear the same serial number, reference is made to this number. The columns for  $x'$ ,  $y'$ , and  $d'$  have not been checked. The correct figures for the whole line are given and should replace the respective lines.

	$\phi$	$\rho$	$\xi_0$	$\eta_0$	$\xi$	$\eta$	$\phi_2$	$\rho_2$
14 027	9°29'	14°22'	2°25'	14°11'	2°21'	14°10'	87°35'	75°50'
19 045	3 25	35 20	2 25	35 17	1 58	35 15	87 35	54 45
44 4.0.13	-90 00	15 25	-15 25	0 00	-15 25	0 00	74 35	90 00
52	The whole line including symbol wrong and to be replaced by							
52 13.0.16	-90 00	38 34½	-38 34½	0 00	-38 34½	0 00	-51 25½	90 00
56 504	-90 00	51 20	-51 20	0 00	-51 20	0 00	-38 40	90 00
58 302	-90 00	56 27	-56 27	0 00	-56 27	0 00	-33 33	90 00
73 112	-47 01	32 58	-25 23	23 52	-23 28	21 47	-64 37	68 13
78 441	-49 09	79 32	-76 16	74 13	-48 04	40 01	-13 46	49 59
85 525	Symbol alone wrong, angles correct							
86 131	Symbol alone wrong, angles correct							
87 122	32 18	46 18	29 12	41 30	22 43½	37 40	60 48	52 20
90 411	-77 48	76 34	-76 16	41 29	-71 56	11 51½	-13 46	78 08½
95	Strike out the form and the whole line							
96 2.10.1	-12 50	83 43	-63 43	83 33	-12 49	75 41	-26 17	14 19
100 681	-41 02	83 55	-80 47	81 52	-40 46	48 35	- 9 13	41 25
109 134	-18 03	34 54	-12 12	33 33	-10 13	32 57	-77 48	57 03
111 125	-24 56	rest of the angles correct						
113 243	31 48	54 13	36 11	49 42	25 19	43 35	53 49	46 25
120	strike out the whole form and line							
121	correct except						60 00	30 00
127	strike out the form and whole line							

Plate III facing page 125, interchange legends and numbers of figures 15 and 16.